# Secrets of the Ocean

This factual, informative, and wholly engrossing book is an up-to-date history of the sea from its earliest beginnings to the very latest discoveries that have been made about its geography its life *forms and its hidden riches.* An immediate critical and popular success, *The Sea Around Us* is unique, both for its authentic, comprehensive information, and for its imaginative, poetic writing.

Beginning with a description of how earth s oceans were formed, Miss Carson s enthralling story tells how life began in the primeval sea, how the hidden mountains and canyons of the ocean deeps are being mapped, and about the breath-taking power of the winds, the waves and the currents, and the paradox of the moving tides. She writes also, of the meaning of the ocean to man—the heritage of the sea that we carry in our bodies—and of the riches to be found in its salty reaches. Marvellously exciting, it is one of the most impressive and illuminating books ever written about a tantalising subject—the ever-changing sea.

*The Sea Around Us* received the 1951 N tional Book Award in non-fiction ud was acclaimed by Thor Heyerdahl, uthor of *Kon Tiki*, as "*sheer pleasure to read a perfect combination of the fascinating science nd the eternal beauty of the sea.*" A movie version of th book won the 1952 Academy Award as the best feature length documentary of the year

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*Front cover photograph by*

*Beyond all things is the ocean*—SENECA



RACHEL L. CARSON

# THE SEA around us

Drawings by Katherine L. Howe



A MENTOP

Published by THE NLW AMERIC

*Published as a MENTOR BOOK*
*By Arrangement with Oxford University Press, Inc.*

*This Mentor edition contains a number of minor editorial revisions by the author*

FIRST PRINTING, JANUARY 1954
SECOND PRINTING, FEBRUARY 1954
THIRD PRINTING, NOVEMBER, 1956
FOURTH PRINTING, FEBRUARY 1957
FIFTH PRINTING, JULY 1958
SIXTH PRINTING, JUNE, 1959

The editors of the following magazines have kindly given permission to reproduce material which originally appeared in the pages of their periodicals
*Atlantic Naturalist, Nature Magazine The New Yorker Science Digest,* and *The Yale Review*

*MENTOR BOOKS are published by*
*The New American Library of World Literature Inc.*
*501 Madison Avenue New York 22 New York*

PRINTED IN THE UNITED STATES OF AMERICA

# Contents

# Acknowledgments

To come alone and unaided with a subject [illegible] and so infinitely mysterious as the sea [illegible] cheerless but impossible, and I have not [illegible] on every hand I have been given the most [illegible] erous help by those whose work is the [illegible] stones of our present knowledge of the sea [illegible] problems of the ocean have read chapters [illegible] fields of study and have made comments [illegible] on their broad understanding. For such [illegible] indebted to Henry B. Bigelow Charles F [illegible] C. Stetson of Harvard University; Martin W [illegible] H. Munk, and Francis P Shepard of the [illegible] Oceanography Robert Cushman Murphy [illegible] Parr of the American Museum of Natural [illegible] Dunbar of Yale University H. A. Marmer of the [illegible] and Geodetic Survey R. C. Hussey of the [illegible] Michigan, George Cobee of the U.S. [illegible] Hilary B. Moore of the University of [illegible]

Many others have cheerfully gone to great [illegible] locate elusive documents, have sent me [illegible] tion and comments, and in many other ways [illegible] my task. Among these are H. U Sverdrup of the [illegible] Institutt in Oslo, L. H. W Cooper of the [illegible] Plymouth, Thor Heyerdahl of Oslo J W [illegible] Eggvin, and Gunnar Rollefsen of the [illegible] Havforskningsinstitutt in Bergen H. Blegvad, [illegible] eral of the International Council for the [illegible] Sea Hans Pettersson of the Oceanografiska [illegible] borg and, in the United States, John Putnam [illegible] National Research Council Richard Fleming of [illegible] graphic Office Daniel Merriman of the B[illegible] graphic Laboratory Edward H. Smith of the Oceanographic Institution, W N Bradley and the U.S. Geological Survey Maurice E [illegible] versity and F R. Fosberg of George

gan to liquefy and Earth became a molten mass. The materials of this mass eventually became sorted out in a definite pattern: the heaviest in the center the less heavy surrounding them, and the least heavy forming the outer rim. This is the pattern which persists today—a central sphere of molten iron, very nearly as hot as it was 2 billion years ago, an intermediate sphere of semi-plastic basalt, and a hard outer shell, relatively quite thin and composed of solid basalt and granite.

The outer shell of the young earth must have been a good many millions of years changing from the liquid to the solid state, and it is believed that, before this change was completed, an event of the greatest importance took place—the formation of the moon. The next time you stand on a beach at night, watching the moon s bright path across the water and conscious of the moon-drawn tides, remember that the moon itself may have been born of a great tidal wave of earthly substance, torn off into space. And remember that if the moon was formed in this fashion, the event may have had much to do with shaping the ocean basins and the continents as we know them.

There were tides in the new earth, long before there was an ocean. In response to the pull of the sun the molten liquids of the earth s whole surface rose in tides that rolled unhindered around the globe and only gradually slackened and diminished as the earthly shell cooled, congealed and hardened. Those believe that the moon is a child of earth say that during an early stage of the earth s development something happened that caused this rolling, viscid tide to gather speed and momentum and to rise to unimaginable heights. Apparently the force that created these greatest tides the earth has ever known was the force of resonance, for at this time the period of the solar tides had come to approach, then equal, the period of the free oscillation of the liquid earth. And so every sun tide was given increased momentum by the push of the earth's oscillation, and each of the twice-daily tides was larger than the one before it. Physicists have calculated that, after 500 years of such monstrous, steadily increasing tides, those on the side toward the sun became too high for stability and a great wave was torn away and hurled into space. But immediately of course, the newly created satellite became subject to physical laws that sent it spinning in an orbit of its own about the earth. This is what we call the moon.

There are reasons for believing that this event took place after the earth s crust had become slightly hardened, instead of during its partly liquid state. There is to this day a great scar on the surface of the globe. This scar or depression holds the Pacific Ocean. According to some geophysicists, the floor of the Pacific is composed of basalt, the substance of the earth s middle layer

le all other oceans are floored with a thin layer of granite, ch makes up most of the earth's outer layer. We immediate- wonder what became of the Pacific's granite covering and most convenient assumption is that it was torn away when moon was formed. There is supporting evidence. The mean sity of the moon is much less than that of the earth (3.3 mpared with 5.5) suggesting that the moon took away none f the earth's heavy core, but that it is composed only of the nite and some of the basalt of the outer layers.

The birth of the moon probably helped shape other regions of world's ocean besides the Pacific. When part of the crust s torn away strains must have been set up in the remaining nite envelope. Perhaps the granite mass cracked open on the e opposite the moon scar. Perhaps, as the earth spun on its s and rushed on its orbit through space, the cracks widened d the masses of granite began to drift apart, moving over a ry slowly hardening layer of basalt. Gradually the outer rtions of the basalt layer became solid and the wandering ntinents came to rest, frozen into place with oceans between em. In spite of theories to the contrary the weight of geo- gic evidence seems to be that the locations of the major ocean sins and the major continental land masses are today much he same as they have been since a very early period of the earth's history.

But this is to anticipate the story for when the moon was rn there was no ocean. The gradually cooling earth was en- loped in heavy layers of cloud, which contained much of the ater of the new planet. For a long time its surface was so hot at no moisture could fall without immediately being recon- erted to steam. This dense, perpetually renewed cloud cover g must have been thick enough that no rays of sunlight could enetrate it. And so the rough outlines of the continents and the mpty ocean basins were sculptured out of the surface of the arth in darkness, in a Stygian world of heated rock and swirl- g clouds and gloom.

As soon as the earth's crust cooled enough, the rains began to ll. Never have there been such rains since that time. They fell ontinuously day and night, days passing into months, into ears, into centuries. They poured into the waiting ocean basins, r falling upon the continental masses, drained away to become ea.

That primeval ocean, growing in bulk as the rains slowly lled its basins, must have been only faintly salt. But the ains were the symbol of the dissolution of the he moment the rains began to fall, the lands way and carried to the sea. It is an endless,

that has never stopped—the dissolving of the rocks, the out of their contained minerals, the carrying of the ments and dissolved minerals to the ocean. And over of time, the sea has grown ever more bitter with the continents.

In what manner the sea produced the mysterious and ful stuff called protoplasm we cannot say. In its warm, dim waters the unknown conditions of temperature and and saltiness must have been the critical ones for the of life from non-life. At any rate they produced the neither the alchemists with their crucibles nor modern sci- in their laboratories have been able to achieve.

Before the first living cell was created, there may have many trials and failures. It seems probable that, within warm saltiness of the primeval sea, certain organic were fashioned from carbon dioxide, sulphur, nitrogen, p phorus, potassium, and calcium. Perhaps these were tion steps from which the complex molecules of arose—molecules that somehow acquired the ability to duce themselves and begin the endless stream of life. But no one is wise enough to be sure.

Those first living things may have been simple microorganisms rather like some of the bacteria we know today—mysterious borderline forms that were not quite plants, not quite animals, barely over the intangible line that separates the non-living from the living. It is doubtful that this first life possessed the substance chlorophyll, with which plants in sunlight transform lifeless chemicals into the living stuff of their tissues. Little sunshine could enter their dim world, penetrating the cloud banks from which fell the endless rains. Probably the sea's first children lived on the organic substances then present in the ocean waters, or like the iron and sulphur bacteria that exist today lived directly on inorganic food.

All the while the cloud cover was thinning, the darkness of the nights alternated with palely illumined days, and finally the sun for the first time shone through upon the sea. By this time some of the living things that floated in the sea must have developed the magic of chlorophyll. Now they were able to take the carbon dioxide of the air and the water of the sea and of these elements, in sunlight, build the organic substances they needed. So the first true plants came into being.

Another group of organisms, lacking the chlorophyll but needing organic food, found they could make a way of life for themselves by devouring the plants. So the first animals arose and from that day to this, every animal in the world has followed the habit it learned in the ancient seas and depends, di-

...rough complex food chains on the plants for food ...

... years passed, and the centuries, and the millions of ... stream of life grew more and more complex. From ...-called creatures, others that were aggregations of ...d cells arose, and then creatures with organs for feed-...ting, breathing, reproducing. Sponges grew on the ...ottom of the sea's edge and coral animals built their ...ons in warm, clear waters. Jellyfish swam and drifted in ... Worms evolved, and starfish, and hard-shelled crea-...th many-jointed legs, the arthropods. The plants, too ...ssed, from the microscopic algae to branched and curi-... fruiting seaweeds that swayed with the tides and were ...d from the coastal rocks by the surf and cast adrift.

...ring all this time the continents had no life. There was lit... induce living things to come ashore, forsaking their all-...lding, all-embracing mother sea. The lands must have been ...k and hostile beyond the power of words to describe. Imag-...a whole continent of naked rock, across which no covering ...tle of green had been drawn—a continent without soil, for ...re were no plants to aid in its formation and bind it to the ...ks with their roots. Imagine a land of stone, a silent land, ex...pt for the sound of the rains and winds that swept across it, ...r there was no living voice, and no living thing moved over ...e surface of the rocks.

Meanwhile, the gradual cooling of the planet, which had first ...ven the earth its hard granite crust, was progressing into its ...eper layers; and as the interior slowly cooled and contracted, ...drew away from the outer shell. This shell, accommodating itself to the shrinking sphere within it, fell into folds and wrinkles—the earth's first mountain ranges.

Geologists tell us that there must have been at least two periods of mountain building (often called "revolutions") in that dim period, so long ago that the rocks have no record of it, so long ago that the mountains themselves have long since been worn away. Then there came ... third great period of upheaval and readjustment of the earth's crust, about a billion years ago, but of all its majestic mountains the only reminders today are the Laurentian hills of eastern Canada, and a great shield of granite over the flat country around Hudson Bay.

The epochs of mountain building only served to speed up the processes of erosion by which continents were worn down and their crumbling rock and contained minerals returned to the sea. The uplifted masses of the mountains were prey to the bitter cold of the upper atmosphere and under the frost and snow and ice the rocks cracked and crumbled. The rains beat with greater violence upon the slopes of

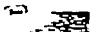

















*Chart of the History of the Earth and Its Life*

desert. We know very little about the first land plants, but they must have been closely related to some of the larger seaweeds that had learned to live in the coastal shallows, developing strengthened stems and grasping, rootlike holdfasts to resist the drag and pull of the waves. Perhaps it was in some coastal low lands, periodically drained and flooded, that some such plants found it possible to survive, though separated from the sea. This also seems to have taken place in the Silurian period.

The mountains that had been thrown up by the Laurentian revolution gradually wore away, and as the sediments were washed from their summits and deposited on the lowlands, great areas of the continents sank under the load. The seas crept out of their basins and spread over the lands. Life fared well and was exceedingly abundant in those shallow, sunlit seas. But with the later retreat of the ocean water into the deeper basins, many creatures must have been left stranded in shallow, landlocked bays. Some of these animals found means to survive on land. The lakes, the shores of the rivers, and the coastal swamps of those days were the testing grounds in which plants and animals either became adapted to the new conditions or perished.

As the lands rose and the seas receded, a strange fishlike creature emerged on the land, and over the thousands of years its fins became legs, and instead of gills it developed lungs. In the Devonian sandstone this first amphibian left its footprint.

On land and sea the stream of life poured on. New forms evolved; some old ones declined and disappeared. On land the mosses and the ferns and the seed plants developed. The reptiles for a time dominated the earth, gigantic, grotesque, and terrifying. Birds learned to live and move in the ocean of air. The first small mammals lurked inconspicuously in hidden crannies of the earth as though in fear of the reptiles.

When they went ashore the animals that took up a land life carried with them a part of the sea in their bodies, a heritage which they passed on to their children and which even today links each land animal with its origin in the ancient sea. Fish, amphibian, and reptile, warm-blooded bird and mammal—each of us carries in our veins a salty stream in which the elements sodium, potassium, and calcium are combined in almost the same proportions as in sea water. This is our inheritance from the day, untold millions of years ago, when a remote ancestor, having progressed from the one-celled to the many-celled stage, first developed a circulatory system in which the fluid was merely the water of the sea. In the same way, our lime-hardened skeletons are a heritage from the calcium-rich ocean of Cambrian time. Even the protoplasm that streams within each cell of our bodies has the chemical structure impressed upon all living matter when the first simple creatures were brought forth in

e true nature of his planet and the long vistas of its history in hich the existence of the race of men has occupied a mere moent of time. The sense of all these things comes to him most early in the course of a long ocean voyage, when he watches ay after day the receding rim of the horizon, ridged and fur owed by waves; when at night he becomes aware of the earth's otation as the stars pass overhead, or when, alone in this world f water and sky he feels the loneliness of his earth in space. And then, as never on land, he knows the truth that his world s a water world, a planet dominated by its covering mantle of ocean, in which the continents are but transient intrusions of and above the surface of the all-encircling sea.

## 2 The Pattern of the Surface

*There is one knows not what sweet mystery about this sea, whose gently awful stirrings seem to speak of some hidden soul beneath.* HERMAN MELVILLE

NOWHERE in all the sea does life exist in such bewildering abundance as in the surface waters. From the deck of a vessel you may look down, hour after hour on the shimmering discs of jellyfish, their gently pulsating bells dotting the surface as far as you can see. Or one day you may notice early in the morning that you are passing through sea that has taken on brick-red color from billions upon billions of microscopic creatures, each of which contains an orange pigment granule. At noon you are still moving through red seas, and when darkness falls the waters shine with an eerie glow from the phosphorescent fires of yet more billions and trillions of these same creatures.

And again you may glimpse not only the abundance but something of the fierce uncompromisingness of sea life when, as you look over the rail and down, down into water of a clear deep green, suddenly there passes a silver shower of finger-long fishlets. The sun strikes a metallic gleam from their flanks as they streak by driving deeper into the green depths with the desperate speed of the hunted. Perhaps you never see the hunters, but you sense their presence as you see the gulls hovering, with eager mewing cries, waiting for the little fish to be driven to the surface.

Or again, perhaps, you may sail for days on end without seeing anything you could recognize as life or the indications of life, day after day of empty water and empty sky and so you may reasonably conclude that there is no spot on ... barren of life as the open ocean. But if you had the ... to tow a fine-meshed net through the seemingly

. 'On dark nights we could see much marine life which we were nable to identify They seemed to be deep-sea fishes approaching the surface at night. Generally we saw it as vaguely phosphorescent bodies, often the size and shape of a dinner plate, but at least one night in the shape of three immense bodies of irregular and changing shape and dimensions which appeared to exceed those of the raft (KON-TIKI measured about 45 by 18 feet) Apart from these greater bodies, we observed occasionally great quantities of phosphorescent plankton, often containing illuminating copepods up to the size of a millimeter or more.'

With these surface waters, through a series of delicately adjusted, interlocking relationships, the life of all parts of the sea is linked. What happens to a diatom in the upper sunlit strata of the sea may well determine what happens to a cod lying on a ledge of some rocky canyon a hundred fathoms below or to a bed of multicolored, gorgeously plumed seaworms carpeting an underlying shoal, or to a prawn creeping over the soft oozes of the sea floor in the blackness of mile-deep water

The activities of the microscopic vegetables of the sea, of which the diatoms are most important, make the mineral wealth of the water available to the animals. Feeding directly on the diatoms and other groups of minute unicellular algae are the marine protozoa, many crustaceans, the young of crabs, barnacles, sea worms, and fishes. Hordes of the small carnivores, the first link in the chain of flesh eaters, move among these peaceful grazers. There are fierce little dragons half an inch long, the sharp-jawed arrowworms. There are gooseberry-like comb jellies, armed with grasping tentacles, and there are the shrimp-like euphausiids that strain food from the water with their bristly appendages. Since they drift where the currents carry them, with no power or will to oppose that of the sea, this strange community of creatures and the marine plants that sustain them are called 'plankton, a word derived from the Greek, meaning 'wandering.

From the plankton the food chains lead on, to the schools of plankton-feeding fishes like the herring, menhaden, and mackerel to the fish-eating fishes like the bluefish and tuna and sharks to the pelagic squids that prey on fishes, to the great whales who, according to their species but not according to their size, may live on fishes, on shrimps, or on some of the smallest of the plankton creatures.

Unmarked and trackless though it may seem to us, the surface of the ocean is divided into definite zones, and the of the surface water controls the distribution of its life. and plankton, whales and squids, birds and sea turtles, linked by unbreakable ties to certain kinds of

undiluted by rain, snow and melting ice. Along the Atlantic coast of the United States, the salinity range from about 33 parts per thousand off Cape Cod to about 36 off Florida is a difference easily perceptible to the senses of human bathers. Ocean temperatures vary from about 28° F in polar seas to 96° in the Persian Gulf, which contains the hottest ocean water in the world. To creatures of the sea, which with few exceptions must match in their own bodies the temperature of the surrounding water, this range is tremendous, and change of temperature is probably the most important single condition that controls the distribution of marine animals.

The beautiful reef corals are a perfect example of the way the inhabitable areas for any particular class of creatures may be established by temperatures. If you took a map of the world and drew a line 30° north of the Equator and another 30° south of it, you would have outlined in general the waters where reef corals are found at the present time. It is true that the remains of ancient coral reefs have been discovered in arctic waters, but this means that in some past ages the climate of these northern seas was tropical. The calcareous structure of the coral reef can be fashioned only in water at least as warm as 70° Fahrenheit. We would have to make one northward extension of our map, where the Gulf Stream carries water warm enough for corals to Bermuda, at 32° north latitude. On the other hand, within our tropical belt, we would have to erase large areas on the west coasts of South America and Africa, where upwelling of cold water from lower ocean levels prevents the growth of corals. Most of the east coast of Florida has no coral reefs because of a cool inshore current, running southward between the coast and the Gulf Stream.

As between tropical and polar regions, the differences in the kinds and abundance of life are tremendous. The warm temperatures of the tropics speed up the processes of reproduction and growth, so that many generations are produced in the time required to bring one to maturity in cold seas. There is more opportunity for genetic mutations to be produced within a given time; hence the bewildering variety of tropical life. Yet in any species there are far fewer individuals than in the colder zones, where the mineral content of the water is richer and there are no dense swarms of surface plankton, like the copepods of the Arctic. The pelagic, or free-swimming forms of the tropics live deeper than those of the colder regions, and so there is less food for large surface-feeders. In the tropics, therefore, the sea birds do not compare in abundance with the clouds of shearwaters, fulmars, auks, whalebirds, albatrosses, and other birds seen over far northern or far southern fishing grounds.

In the cold-water communities of the polar seas, fewer of the

animals have swimming larvae. Generation after generation set tle down near the parents, so that large areas of bottom may be covered with the descendants of a very few animals. In the Barents Sea a research vessel once brought up more than a ton of one of the siliceous sponges at a single haul, and enormous patches of a single species of annelid worm carpet the east co of Spitsbergen. Copepods and swimming snails fill the surface waters of the cold seas, and lure the herring and the mackerel, the flocks of sea birds, the whales, and the seals.

In the tropics, then, sea life is intense, vivid, and infinitely varied. In cold seas life proceeds at a pace slowed by the icy water in which it exists, but the mineral richness of these waters (largely a result of seasonal overturn and consequent mixing) makes possible the enormous abundance of the forms that inhabit them. For a good many years it has been said categorically that the total productivity of the colder temperate and polar seas is far greater than the tropical. Now it is becoming plain that there are important exceptions to this statement. In certain tropical and subtropical waters, there are areas where the sheer abundance of life rivals the Grand Banks or the Barents Sea or any antarctic whaling ground. Perhaps the best examples are the Humboldt Current, off the west coast of South America, and the Benguela Current, off the west coast of Africa. In both currents, upwelling of cold, mineral-laden from deeper layers of the sea provides the fertilizing to sustain the great food chains.

And wherever two currents meet, especially if they differ sharply in temperature or salinity there are zones of great turbulence and unrest, with water sinking or rising up from the depths and with shifting eddies and foam lines at the surface. At such places the richness and abundance of marine life reveals itself most strikingly This changing life, seen as his ship cut across the pathways of the great currents of the Pacific and the Atlantic, was described with vivid detail by S. C. Brooks

"Within a few degrees of the equator the scattered cumulus clouds become thicker and grayer a confused swell makes up, rain squalls come and go and birds appear At first there is only a greater abundance of storm petrels, with here and there petrels of other kinds hunting along utterly indifferent to the ship, or small groups of tropic birds flying along with the ship off to one side or high overhead. Then scattered groups of various petrels appear and finally for an hour or two there are birds on every hand. If one is not too far from land, a few hundred miles perhaps, as in the case of the south equatorial drift north of the Marquesas, one may also see multitudes of sooty or crested terns. Occasionally one sees the grayish blue form of a shark gliding along, or a big purplish-brown hammerhead lazily twist-

ing around as though trying to get a better view of the ship. Flying fish, while not so closely localized as the birds, are breaking the water every few seconds, and bewitch the beholder by their myriad sizes, shapes, and antics, and their bewildering patterns and shades of deep brown, opal blue, yellow and purple. Then the sun comes out again, the sea takes on its deep tropical blue, the birds become more and more scarce, and gradually as the ship moves on, *the ocean resumes its desert aspect.*

"If it were daylight all the time this same sequence might be seen in a more or less striking fashion twice or perhaps even three or four times. Inquiry soon reveals that this sequence marks the time of passing the edge of one of the great currents

"In the North Atlantic ship lanes the same play is staged with different actors. Instead of the equatorial currents there are the Gulf Stream and its continuation, the North Atlantic Drift, and the Arctic Current, instead of confused swell and squalls of rain there are slicks and fogs. Tropic-birds are replaced by jaegers and skuas and different species of the petrel group, usually here spoken of as shearwaters and fulmars, are flying or swimming about, often in great flocks Here, too, perhaps, one sees less of sharks and more of porpoise racing with the cut-water or doggedly hurrying, school after school, toward some unguessable objective. The flashing black and white of the young orcas, or the distant sodden spurt and lazy drift of a whale spouting, lend life to the water as do the antics of flying fish, distant though they be from their traditional home in the tropics One may pass from the blue water of the Stream, with floating gulf weed (Sargassum) and perhaps here and there the iridescent float of a Portuguese man-of-war into the gray-green water of the Arctic Current with its thousands of jelly fish, and in a few hours back gain into the Stream. Each time, at the margin, one is likely to see the surface display of that abundance of lif which has made the Grand Banks one of the great fisheries of the world.

The mid-ocean regions, bounded by the currents that sweep around the ocean basins, are in general the deserts of the sea. There are few birds and few surface-feeding fishes, and indeed there is little surface plankton to attract them. The lif of these regions is largely confined to deep water The Sargasso Sea is an exception, not matched in the anticyclonic centers of other ocean basins. It is so different from any other place on earth that it may well be considered definite geographic region. A line drawn from the mouth of Chesapeake B y to Gibraltar would skirt its northern border another from Haiti to Dakar would mark its southern boundary It lies all about Bermuda and

*From The Condor, vol. 36, no. 1, Sept.-Oct. 1934, pp. 186-7*

tends more than halfway across the Atlantic, its entire
ing roughly as large as the United States. The Sargasso,
its legendary terrors for sailing ships, is a creation of the
currents of the North Atlantic that encircle it and
the millions of tons of floating sargassum weed from
place derives its name, and all the weird assemblage
that live in the weed.

The Sargasso is a place forgotten by the winds,
by the strong flow of waters that girdle it as with a river. U
the seldom-clouded skies, its waters are warm and heavy
salt. Separated widely from coastal rivers and from polar
there is no inflow of fresh water to dilute its saltiness; the
influx is of saline water from the adjacent currents,
from the Gulf Stream or North Atlantic Current as it
from America to Europe. And with the little, inflowing
of surface water come the plants and animals
years have drifted in the Gulf Stream.

The sargassum weeds are brown algae belonging to
species. Quantities of the weeds live attached to reefs (
outcroppings off the coasts of the West Indies and
Many of the plants are torn away by storms, especially
the hurricane season. They are picked up by the Gulf
and are drifted northward. With the weeds go, as
passengers, many small fishes, crabs, shrimps, and
larvae of assorted species of marine creatures, whose
been the coastal banks of sargassum weed.

Curious things happen to the animals that have ridden on
sargassum weed into a new home. Once they lived near
sea's edge, a few feet or a few fathoms below the surface,
never far above a firm bottom. They knew the rhythmic
ments of waves and tides. They could leave the shelter of
weeds at will and creep or swim about over the bottom in
of food.

Now in the middle of the ocean, they are in a new
The bottom lies two or three miles below them. Those who are
poor swimmers must cling to the weed, which now represents a
life raft, supporting them above the abyss. Over the ages since
their ancestors came here, some species have developed special
organs of attachment, either for themselves or for their eggs, so
that they may not sink into the cold, dark water far below. The
flying fish make nests of the weed to contain their eggs, which
bear an amazing resemblance to the sargassum floats or "berries.

Indeed, many of the little marine beasts of the weedy jungle
seem to be playing an elaborate game of disguise in which each
is camouflaged to hide it from the others. The Sargasso sea slug
—a snail without a shell—has a soft, shapeless brown body spot
ted with dark-edged circles and fringed with flaps and folds of

skin, so that as it creeps over the weed in search of prey it can scarcely be distinguished from the vegetation. One of the fiercest carnivores of the place, the sargassum fish Pterophryne, has copied with utmost fidelity the branching fronds of the weed, its golden berries, its rich brown color and even the white dots of encrusting worm tubes. All these elaborate bits of mimicry are indications of the fierce internecine wars of the Sargasso jungles, which go on without quarter and without mercy for the weak or the unwary

In the science of the sea there has been a long-standing controversy about the origin of the drifting weeds of the Sargasso Sea. Some have held that the supply is maintained by weeds recently torn away from coastal beds others say that the rather limited sargassum fields of the West Indies and Florida cannot possibly supply the immense area of the Sargasso. They believe that we find here a self-perpetuating community of plants that have become adapted to life in the open sea, needing no roots or hold-fasts for attachment, and able to propagate vegetatively Probably there is truth in both ideas. New plants do come in each year in small numbers, and now cover an immense area because of their very long life once they have reached this quiet central region of the Atlantic.

It takes about half a year for the plants torn from West Indian shores to reach the northern border of the Sargasso, perhaps several years for them to be carried into the inner parts of this area. Meanwhile, some have been swept onto the shores of North America by storms, others have been killed by cold during the passage from offshore New England across the Atlantic, where the Gulf Stream comes into contact with waters from the Arctic. For the plants that reach the calm of the Sargasso, there is virtual immortality A. E. Parr of the American Museum has recently suggested that the individual plants may live, some for decades, others for centuries, according to their species. It might well be that some of the very weeds you would see if you visited the place today were seen by Columbus and his men. Here, in the heart of the Atlantic, the weed drifts endlessly growing, reproducing vegetatively by a process of fragmentation. Apparently almost the only plants that die are the ones that drift into unfavorable conditions around the edges of the Sargasso or are picked up by outward-moving currents.

Such losses are balanced, or possibly a little more than balanced, by the annual addition of weeds from distant coasts. It must have taken eons of time to accumulate the present enormous quantities of weed, which Parr estimates as about 10 million tons. But this, of course is distributed over so large an area that most of the Sargasso is open water The dense fields of weeds waiting to entrap a vessel never existed except

imaginations of sailors, and the gloomy hulks of vessels to endless drifting in the clinging weed are only the ghosts things that never were.

# 3 The Changing Year

*Thus with the year seasons return.*
MILTON

For the sea as a whole, the alternation of day and night, passage of the seasons, the procession of the years, are lost in vastness, obliterated in its own changeless eternity But the face waters are different. The face of the sea is always changing Crossed by colors, lights, and moving shadows, sparkling in sun, mysterious in the twilight, its aspects and its moods hour by hour The surface waters move with the tides, stir to breath of the winds, and rise and fall to the endless, hurry forms of the waves. Most of all, they change with the of the seasons. Spring moves over the temperate lands of Northern Hemisphere in a tide of new life, of pushing shoots and unfolding buds, all its mysteries and meanings sym bolized in the northward migration of the birds, the of sluggish amphibian life as the chorus of frogs rises again from the wet lands, the different sound of the wind which stirs the young leaves where a month ago it rattled the bare branches. These things we associate with the land, and it is easy to suppose that at sea there could be no such feeling of advancing spring. But the signs are there, and seen with understanding eye, they bring the same magical sense of awakening.

In the sea, as on land, spring is a time for the renewal of life. During the long months of winter in the temperate zones the surface waters have been absorbing the cold. Now the heavy water begins to sink, slipping down and displacing the warmer layers below. Rich stores of minerals have been accumulating on the floor of the continental shelf—some freighted down the rivers from the lands; some derived from sea creatures that have died and whose remains have drifted down to the bottom some from the shells that once encased a diatom, the streaming protoplasm of a radiolarian, or the transparent tissues of a pteropod. Nothing is wasted in the sea every particle of material is used over and over again, first by one creature, then by another And when in spring the waters are deeply stirred, the warm bottom water brings to the surface a rich supply of minerals, ready for use by new forms of life.

Just as land plants depend on minerals in the soil for their

growth, every marine plant, even the smallest, is dependent upon the nutrient salts or minerals in the sea water. Diatoms must have silica, the element of which their fragile shells are fashioned. For these and all other microplants, phosphorus is an indispensable mineral. Some of these elements are in short supply and in winter may be reduced below the minimum necessary for growth. The diatom population must tide itself over this season as best it can. It faces a stark problem of survival with no opportunity to increase, a problem of keeping alive the spark of life by forming tough protective spores against the stringency of winter a matter of existing in dormant state in which no demands shall be made on an environment that already withholds all but the most meager necessities of life. So the diatoms hold their place in the winter sea, like seeds of wheat in a field under snow and ice, the seeds from which the spring growth will come.

These, then, are the elements of the vernal blooming of the sea, the 'seeds of the dormant plants, the fertilizing chemicals, the warmth of the spring sun.

In a sudden awakening, incredible in its swiftness, the simplest plants of the sea begin to multiply. Their increase is of astronomical proportions. The spring sea belongs at first to the diatoms and to all the other microscopic plant life of the plankton. In the fierce intensity of their growth they cover vast areas of ocean with a living blanket of their cells. Mile after mile of water may appear red or brown or green, the whole surface taking on the color of the infinitesimal grains of pigment contained in each of the plant cells.

The plants have undisputed sway in the sea for only a short time. Almost at once their own burst of multiplication is matched by a similar increase in the small animals of the plankton. It is the spawning time of the copepod and the glassworm, the pelagic shrimp and the winged snail. Hungry swarms of these little beasts of the plankton roam through the waters, feeding on the abundant plants and themselves falling prey to larger creatures. Now in the spring the surface waters become a vast nursery. From the hills and valleys of the continent's edge lying far below and from the scattered shoals and banks, the eggs or young of many of the bottom animals rise to the surface of the sea. Even those which, in their maturity will sink down to a sedentary life on the bottom, spend the first weeks of life as freely swimming hunters of the plankton. So as spring progresses new batches of larvae rise into the surface each day the young of fishes and crabs and mussels and tube worms, mingling for time with the regular members of the plankton.

Under the steady and voracious grazing, the grasslands of the surface are soon depleted. The diatoms beer

scarce, and with them the other simple plants. Still there brief explosions of one or another form, when in a sudden of cell division it comes to claim whole areas of the sea for own. So, for a time each spring, the waters may becom blotched with brown, jellylike masses, and the fishermen's net come up dripping a brown slime and containing no fish, herring have turned away from these waters as though in loath- ing of the viscid, foul-smelling algae. But in less time than between the full moon and the new the spring flowering Phaeocystis is past and the waters have cleared again.

In the spring the sea is filled with migrating fishes, some of them bound for the mouths of great rivers, which they ascend to deposit their spawn. Such are the spring-run ch coming in from the deep Pacific feeding grounds to breast rolling flood of the Columbia, the shad moving in to the C peake and the Hudson and the Connecticut, the alewives ing a hundred coastal streams of New England, the salmon ing their way to the Penobscot and the Kennebec. For or years these fish have known only the vast spaces of the Now the spring sea and the maturing of their own bodies them back to the rivers of their birth.

Other mysterious comings and goings are linked with the ad- vance of the year. Capelin gather in the deep, cold water of Barents Sea, their shoals followed and preyed upon by flocks auks, fulmars, and kittiwakes. Cod approach the banks of ten, and gather off the shores of Iceland. Birds whose winter feeding territory may have encompassed the whole Atlantic or the whole Pacific converge upon some small island, the entire breeding population arriving within the space of a few days. Whales suddenly appear off the slopes of the coastal banks where the swarms of shrimplike krill are spawning, the whales having come from no one knows where, by no one knows what route.

With the subsiding of the diatoms and the completed spawn- ing of many of the plankton animals and most of the fish, life in the surface waters slackens to the slower pace of midsummer. Along the meeting places of the currents the pale moon jelly Aurelia gathers in thousands, forming sinuous lines or windrows across miles of sea, and the birds see their pale forms shimmer- ing deep down in the green water. By midsummer the large red jellyfish Cyanea may have grown from the size of a thimble to that of an umbrella. The great jellyfish moves through the sea with rhythmic pulsations, trailing long tentacles and as likely as not shepherding a little group of young cod or haddock, which find shelter under its bell and travel with it.

A hard, brilliant, coruscating phosphorescence often illumi- nates the summer sea. In waters where the protozoan Noctiluca is abundant it is the chief source of this summer luminescence,

causing fishes, squids, or dolphins to fill the water with racing flames and to clothe themselves in a ghostly radiance. Or again the summer sea may glitter with a thousand thousand moving pinpricks of light, like an immense swarm of fireflies moving through a dark wood. Such an effect is produced by a shoal of the brilliantly phosphorescent shrimp Meganyctiphanes, a creature of cold and darkness and of the places where icy water rolls upward from the depths and bubbles with white ripplings at the surface.

Out over the plankton meadows of the North Atlantic the dry twitter of the phalaropes, small brown birds, wheeling and turning, dipping and rising, is heard for the first time since early spring. The phalaropes have nested on the arctic tundras, reared their young, and now the first of them are returning to the sea. Most of them will continue south over the open water far from land, crossing the equator into the South Atlantic. Here they will follow where the great whales lead, for where the whales are there also are the swarms of plankton on which these strange little birds grow fat.

As the fall advances, there are other movements, some in the surface, some hidden in the green depths, that betoken the end of summer. In the fog-covered waters of Bering Sea, down through the treacherous passes between the islands of the Aleutian chain and southward into the open Pacific, the herds of fur seals are moving. Left behind are two small islands, treeless bits of volcanic soil thrust up into the waters of Bering Sea. The islands are silent now but for the several months of summer they resounded with the roar of millions of seals come ashore to bear and rear their young—all the fur seals of the eastern Pacific crowded into a few square miles of bare rock and crumbling soil. Now once more the seals turn south, to roam down along the sheer underwater cliffs of the continent's edge, where the rocky foundations fall away steeply into the deep sea. Here, in a blackness more absolute than that of arctic winter the seals will find rich feeding as they swim down to prey on the fishes of this region of darkness.

Autumn comes to the sea with a fresh blaze of phosphorescence, when every wave crest is aflame. Here and there the whole surface may glow with sheets of cold fire, while below schools of fish pour through the water like molten metal. Often the autumnal phosphorescence is caused by a fall flowering of the dinoflagellates, multiplying furiously in a short lived repetition of their vernal blooming.

Sometimes the meaning of the glowing water is ominous. Off the Pacific coast of North America, it may mean that the filled with the dinoflagellate Gonyaulax, minute plant contains poison of strange and terrible virulence. A

days after Gonyaulax comes to dominate the coastal p[lankton] some of the fishes and shellfish in the vicinity become toxic. [This] is because, in their normal feeding, they have strained the [poi]sonous plankton out of the water. Mussels accumulate Gonyaulax toxins in their livers, and the toxins react on human nervous system with an effect similar to that of [strych]nine. Because of these facts, it is generally understood along Pacific coast that it is unwise to eat shellfish taken from c[oasts] exposed to the open sea where Gonyaulax may be abundant, summer or early fall. For generations before the white [men] came, the Indians knew this. As soon as the red streaks [ap]peared in the sea and the waves began to flicker at night with mysterious blue-green fires, the tribal leaders forbade the [eating] of mussels until these warning signals should have passed. T[hey] even set guards at intervals along the beaches to warn inlan[d]ers who might come down for shellfish and be unable to [read] the language of the sea.

But usually the blaze and glitter of the sea, whatever [its mean]ing for those who produce it, implies no menace to man. [Seen] from the deck of [a] vessel in open ocean, a tiny man-made [ob]servation point in the vast world of sea and sky, it has an [eerie] and unearthly quality. Man, in his vanity, subconsciously [at]tributes a human origin to any light not [o]f moon or stars or [sun]. Lights on the shore, lights moving over the water, mean li[ghts] kindled and controlled by other men, serving purposes [under]standable to the human mind. Yet here are lights that flash [and] fade [a]w[a]y, lights that come and go for reasons meaningless [to] man, lights that have been doing this very thing [over the eons] of time in which there were no men to stir in vague disquiet.

On such a night of phosphorescent display Charles Darwin stood on the deck of the *Beagle* as she plowed southward through the Atlantic off the coast of Brazil.

The sea from its extreme luminousness presented a wonderful and most beautiful appearance [he wrote in his diary]. Every part of the water which by day is seen as foam, glowed with a pale light. The vessel drove before her bows two billows of liquid phosphorus, and in her wake was a milky train. As far as the eye reached the crest of every wave was bright, and from the reflected light, the sky just above the horizon was not so utterly dark as the rest of the Heavens. It was impossible to behold this plain of matter as it were melted and consuming by heat, without being reminded of Milton's description of the regions of Chaos and Anarchy.

Like the blazing colors [o]f the autumn leaves before they wither and fall, the autumnal phosphorescence betokens the [ap]-

From Charles Darwin's Diary of the Voyage of H.M.S. Beagle, edited by Nora Barlow. 1934 edition, Cambridge University Press, p. 107

approach of winter. After their brief renewal of life the flagellates and the other minute algae dwindle away to a scattered few; so do the shrimps and the copepods, the glassworms and the comb jellies. The larvae of the bottom fauna have long since completed their development and drifted away to take up whatever existence is their lot. Even the roving fish schools have deserted the surface waters and have migrated into warmer latitudes or have found equivalent warmth in the deep, quiet waters along the edge of the continental shelf. There the torpor of semi-hibernation descends upon them and will possess them during the months of winter.

The surface waters now become the plaything of the winter gales. As the winds build up the giant storm waves and roar along their crests, lashing the water into foam and flying spray, it seems that life must forever have deserted this place.

For the mood of the winter sea, read Joseph Conrad's description:

'The greyness of the whole immense surface, the wind furrows upon the faces of the waves, the great masses of foam, tossed about and waving, like matted white locks, give to the sea in a gale an appearance of hoary age, lustreless, dull, without gleams, as though it had been created before light itself.'

But the symbols of hope are not lacking even in the grayness and bleakness of the winter sea. On land we know that the apparent lifelessness of winter is an illusion. Look closely at the bare branches of a tree, on which not the palest gleam of green can be discerned. Yet, spaced along each branch are the leaf buds, all the spring's magic of swelling green concealed and safely preserved under the insulating, overlapping layers. Pick off a piece of the rough bark of the trunk; there you will find hibernating insects. Dig down through the snow into the earth. There are the eggs of next summer's grasshoppers; there are the dormant seeds from which will come the grass, the herb, the oak tree.

So, too, the lifelessness, the hopelessness, the despair of the winter sea are an illusion. Everywhere are the assurances that the cycle has come to the full, containing the means of its own renewal. There is the promise of a new spring in the very iciness of the winter sea, in the chilling of the water, which must, before many weeks, become so heavy that it will plunge downward, precipitating the overturn that is the first act in the drama of spring. There is the promise of new life in the small plant-like things that cling to the rocks of the underlying bottom, the almost formless polyps from which, in spring, a new generation of jellyfish will bud off and rise into the surface waters. T

From *The Mirror of the Sea*, Kent edition, 1925, Doubleday I

is unconscious purpose in the sluggish forms of the ... hibernating on the bottom, safe from the surface storms, ... sustained in their tiny bodies by the extra store of fat ... which they went into this winter sleep.

Already from the gray shapes of cod that have moved, ... seen by man, through the cold sea to their spawning places, glassy globules of eggs are rising into the surface waters. In the harsh world of the winter sea, these eggs will begin swift divisions by which a granule of protoplasm becomes a l... ing fishlet.

Most of all, perhaps, there is assurance in the fine dust of ... that remains in the surface waters, the invisible spores of diatoms, needing only the touch of warming sun and chemicals to repeat the magic of spring.

## 4 The Sunless Sea

*Where great whales come sailing by*
*Sail and sail, with unshut eye*

MATTHEW ARNOLD

BETWEEN the sunlit surface waters of the open sea and ... den hills and valleys of the ocean floor lies the least kno... region of the sea. These deep, dark waters, with all their ... teries and their unsolved problems, cover a very considerabl... part of the earth. The whole world ocean extends over three-fourths of the surface of the globe. If we subtract the shallow areas of the continental shelves and the scattered banks and shoals, where at least the pale ghost of sunlight moves over the underlying bottom, there still remains about half the earth that is covered by miles-deep, lightless water that has been dark since the world began.

This region has withheld its secrets more obstinately than any other. Man, with all his ingenuity has been able to venture only to its threshold. Carrying tanks of compressed air he can swim down to depths of about 300 feet. He can descend about 500 feet wearing a diving helmet and a rubberized suit. Only a few men in all the history of the world have had the experience of descending, alive, beyond the range of visible light. The first to do so were William Beebe and Otis Barton in the bathysphere; they reached a depth of 3028 feet in the open ocean off Bermuda, in the year 1934. Barton alone, in the summer of 1949, descended to a depth of 4500 feet off California, in a steel sphere of somewhat different design, and in 1953 French div...

ers penetrated *depths greater than a mile, existing for several* hours in a zone of cold and darkness where the presence of living man had never before been known.

*Although only a fortunate few can ever visit the deep sea, the* precise instruments of the oceanographer recording light penetration, pressure, salinity and temperature, have given us the materials with which *to reconstruct in imagination these eerie,* forbidding regions. Unlike the surface waters, which are sensitive to every gust of wind, which know day and night, respond to the pull of sun and moon, *and change as the seasons change, the* deep waters are a place where change comes slowly, if at all. Down beyond the reach of the sun's rays, there is no alternation of light and darkness. *There is rather an endless night, as old as* the sea itself. For most of its creatures, groping their way endlessly through its black waters, it must be a place of hunger where food is scarce and hard to find, a *shelterless place where* there is no sanctuary from ever-present enemies, where one can only move on and on, from birth to death, through the darkness, confined as in a prison to his own particular layer of the sea.

They used to say that nothing could live in the deep sea. It was a belief that must have been easy to accept, for without proof to the contrary how could anyone conceive of life in such a place?

A century ago the British biologist Edward Forbes wrote: As we descend deeper and deeper into this region, the inhabitants become more and more modified, and fewer and fewer indicating our approach to an abyss where life is either extinguished, or exhibits but a few sparks to mark its lingering presence. Yet Forbes urged further exploration of 'this vast deep-sea region to settle forever the question of the existence of life at great depths.

Even then, the evidence was accumulating. Sir John Ross, during his exploration of the arctic seas in *1818*, had brought up from a depth of 1000 fathoms mud in which there were worms, 'thus proving there was animal life in the bed of the ocean notwithstanding the darkness, *stillness, silence, and immense pressure* produced by more than mile of superincumbent water

Then from the surveying ship *Bulldog* examining a proposed *northern route for a cable from* Faroe to Labrador in 1860, came another report. The *Bulldog's* sounding line, which at one place had been allowed to lie for some time on the bottom at a depth of 1 60 fathoms, came up with 13 starfish clinging to it. Through these starfish, the ship's naturalist wrote 'the deep has sent forth the long coveted message. But not all the zoo-
of the day were prepared to accept the
asserted that the starfish had convulsively ...
somewhere on the way back to the surface.

In the same year 1860, a cable in the Mediterranean raised for repairs from a depth of 1200 fathoms. It was be heavily encrusted with corals and other sessile animals had attached themselves at an early stage of development grown to maturity over a period of months or years. There not the slightest chance that they had become entangled is cable as it was being raised to the surface.

Then the *Challenger* the first ship ever equipped for oceanographic exploration, set out from England in the year 1872 ar traced a course around the globe. From bottoms lying miles of water from silent deeps carpeted with red clay ooze, and from all the lightless intermediate depths, net-haul net-haul of strange and fantastic creatures came up and spilled out on the decks. Poring over the weird beings brought up for the first time into the light of day beings man had ever seen before, the *Challenger* scientists realized life existed even on the deepest floor of the abyss.

The recent discovery that a living cloud of some unl creatures is spread over much of the ocean at a depth of hundred fathoms below the surface is the most exciting that has been learned about the ocean for many years.

When, during the first quarter of the twentieth century sounding was developed to allow ships while under way record the depth of the bottom, probably no one suspected th it would also provide a means of learning something deep-sea life But operators of the new instruments soon covered that the sound waves, directed downward from the ship like a beam of light, were reflected back from any solid object they met. Answering echoes were returned from intermediate depths, presumably from schools of fish, whales, or submarines, then a second echo was received from the bottom.

These facts were so well established by the late 1930's that fishermen had begun to talk about using their fathometers to search for schools of herring. Then the war brought the whole subject under strict security regulations, and little more was heard about it. In 1946 however the United States Navy issued a significant bulletin. It was reported that several scientists, working with sonic equipment in deep water off the California coast, had discovered a widespread 'layer' of some sort, which gave back an answering echo to the sound waves. This reflecting layer seemingly suspended between the surface and the floor of the Pacific, was found over an area 300 miles wide. It lay from 1000 to 1500 feet below the surface. The discovery was made by three scientists, C. F Eyring, R. J Christensen, and R. W Raitt, aboard the U.S.S. *Jasper* in 1942, and for a time this mysterious phenomenon, of wholly unknown nature, was called the ECR layer Then in 1945 Martin W Johnson,

marine biologist of the Scripps Institution of Oceanography made a further discovery which gave the first clue to the nature of the layer. Working aboard the vessel, *E. W. Scripps*, Johnson found that whatever sent back the echoes moved upward and downward in rhythmic fashion, being found near the surface at night, in deep water during the day. This discovery disposed of speculations that the reflections came from something inanimate, perhaps a mere physical discontinuity in the water, and showed that the layer is composed of living creatures capable of controlled movement.

From this time on, discoveries about the sea's 'phantom bottom' came rapidly. With widespread use of echo-sounding instruments, it has become clear that the phenomenon is not something peculiar to the coast of California alone. It occurs almost universally in deep ocean basins—drifting by day at a depth of several hundred fathoms, at night rising to the surface, and again, before sunrise, sinking into the depths.

On the passage of the U.S.S. *Henderson* from San Diego to the Antarctic in 1947, the reflecting layer was detected during the greater part of each day at depths varying from 150 to 450 fathoms, and on a later run from San Diego to Yokosuka, Japan, the *Henderson's* fathometer again recorded the layer every day, suggesting that it exists almost continuously across the Pacific.

During July and August 1947, the U.S.S. *Nereus* made a continuous fathogram from Pearl Harbor to the Arctic and found the scattering layer over all deep waters along this course. It did not develop, however, in the shallow Bering and Chuckchee seas. Sometimes in the morning, the *Nereus'* fathogram showed two layers, responding in different ways to the growing illumination of the water; both descended into deep water, but there was an interval of twenty miles between the two descents.

Despite attempts to sample it or photograph it, no one is sure what the layer is, although the discovery may be made any day. There are three principal theories, each of which has its group of supporters. According to these theories, the sea's phantom bottom may consist of small planktonic shrimps, of fishes, or of squids.

As for the plankton theory, one of the most convincing arguments is the well-known fact that many plankton creatures make regular vertical migrations of hundreds of feet, rising toward the surface at night, sinking down below the zone of light penetration very early in the morning. This is, of course, exactly the behavior of the scattering layer. Whatever ... it is ... pparently strongly repelled by sunlight. The ... the layer seem almost to be held prisoner at the

the end—of the sun's rays throughout the hours of daylight waiting only for the welcome return of darkness to hurry upward into the surface waters. But what is the power that repels and what the attraction that draws them surfaceward when the inhibiting force is removed? Is it comparative safety from enemies that makes them seek darkness? Is it more abundant food near the surface that lures them back under cover of night?

Those who say that fish are the reflectors of the sound waves usually account for the vertical migrations of the layer as suggesting that the fish are feeding on planktonic shrimp and are following their food. They believe that the air bladder of a fish is, of all structures concerned, most likely from its construction to return a strong echo. There is one outstanding difficulty in the way of accepting this theory: we have no other evidence that concentrations of fish are universally present in the oceans. In fact, almost everything else we know suggests that the dense populations of fish live over the continental shelves or in certain very definite determined zones of the open ocean where food is particularly abundant. If the reflecting layer is finally proved to be composed of fish, the prevailing views of fish distribution will have to be radically revised.

The most startling theory (and the one that seems to have fewest supporters) is that the layer consists of concentrations of squid, hovering below the illuminated zone of the sea awaiting the arrival of darkness in which to resume their raids into the plankton-rich surface waters. Proponents of this theory argue that squid are abundant enough, and of wide enough distribution, to give the echoes that have been picked up almost everywhere from the equator to the two poles. Squid are known to be the sole food of the sperm whale, found in the open oceans in all temperate and tropical waters. They also form the exclusive diet of the bottlenosed whale and are eaten extensively by most other toothed whales, by seals, and by many sea birds. All these facts argue that they must be prodigiously abundant.

It is true that men who have worked close to the sea surface at night have received vivid impressions of the abundance and activity of squids in the surface waters in darkness. Long ago Johan Hjort wrote:

'One night we were hauling long lines on the Faroe slope, working with an electric lamp hanging over the side in order to see the line, when like lightning flashes one squid after another shot towards the light . . . In October 1902 we were one night steaming outside the slopes of the coast banks of Norway, and for many miles we could see the squids moving in the

surface waters like luminous bubbles, resembling large milky white electric lamps being constantly lit and extinguished.

Thor Heyerdahl reports that at night his raft was literally bombarded by squids and Richard Fleming says that in his oceanographic work off the coast of Panama it was common to see immense schools of squid gathering at the surface at night and leaping upward toward the lights that were used by the men to operate their instruments. But equally spectacular surface displays of shrimp have been seen, and most people find it difficult to believe in the ocean-wide abundance of squid.

Deep-water photography holds much promise for the solution of the mystery of the phantom bottom. There are technical difficulties, such as the problem of holding a camera still as it swings at the end of a long cable, twisting and turning, suspended from a ship which itself moves with the sea. Some of the pictures so taken look as though the photographer has pointed his camera at a starry sky and swung it in an arc as he exposed the film. Yet the Norwegian biologist Gunnar Rollefson had an encouraging experience in correlating photography with echograms. On the research ship *Johan Hjort* off the Lofoten Islands, he persistently got reflection of sound from schools of fish in 20 to 30 fathoms. A specially constructed camera was lowered to the depth indicated by the echogram. When developed, the film showed moving shapes of fish at a distance, and large and clearly recognizable cod appeared in the beam of light and hovered in front of the lens.

Direct sampling of the layer is the logical means of discovering its identity but the problem is to develop large nets that can be operated rapidly enough to capture swift-moving animals. Scientists at Woods Hole Massachusetts, have towed ordinary plankton nets in the layer and have found that euphausiid shrimps, glassworms, and other deep-water plankton are concentrated there but there is still a possibility that the layer itself may actually be made up of larger forms feeding on the shrimps—too large or swift to be taken in the presently used nets. New nets may give the answer Television is another possibility

Shadowy and indefinite though they be, these recent indications of an abundant life at mid-depths gree with the reports of the only observers who have actually isited comparable depths and brought back eyewitness accounts of what they saw Wil liam Beebe's impressions from the bathysphere were of a life far more abundant and varied than he had been prepared to find, although, over period of six years, he had made many hundreds of net hauls in the same area. More than quarter of mile down, he reported aggregations of living things "a thick

From *The Depths of the Ocean*, by Sir John Murray and Johan H[illegible], Macmillan [illegible] Co., p. [illegible]

as I have ever seen them. At half a mile—the deepest of the bathysphere—Dr Beebe recalled that 'there was no stant when a mist of plankton was not swirling in path of the beam.

The existence of an abundant deep-sea fauna was di ered, probably millions of years ago, by certain whales and also, it now appears, by seals. The ancestors of all whales, we know by fossil remains, were land mammals. They must have been predatory beasts, if we are to judge by their powerful jaws and teeth. Perhaps in their foragings about the deltas of great rivers or around the edges of shallow seas, they discovered the dance of fish and other marine life and over the formed the habit of following them farther and farther into sea. Little by little their bodies took on form more suitable aquatic life their hind limbs were reduced to rudiments, whi may be discovered in a modern whale by dissection, and forelimbs were modified into organs for steering and bal

Eventually the whales, as though to divide the sea's resources among them, became separated into three groups plankton-eaters, the fish-eaters, and the squid-eaters. The ton-eating whales can exist only where there are dense of small shrimp or copepods to supply their enormous food quirements. This limits them, except for scattered areas, to and antarctic waters and the high temperate latitudes. Fish ing whales may find food over a somewhat wider range ocean, but they are restricted to places where there are mous populations of schooling fish. The blue water of tropics and of the open ocean basins offers little to either these groups. But that immense, square-headed, formidab toothed whale known as the cachalot or sperm whale d ered long ago what men have known for only a short ti that hundreds of fathoms below the almost untenanted waters of these regions there is an abundant animal life. sperm whale has taken these deep waters for his hunti grounds his quarry is the deep-water population of squids including the giant squid Architeuthis, which lives pelagically a depths of 1500 feet or more. The head of the sperm whale is often marked with long stripes, which consist of a great number of circular scars made by the suckers of the squid. From this evidence we can imagine the battles that go on, in the darkness of the deep water between these two huge creatures—the sperm whale with its 70-ton bulk, the squid with a body as long as 30 feet, and writhing, grasping arms extending the total length of the animal to perhaps 50 feet.

The greatest depth at which the giant squid lives is not definitely known, but there is one instructive piece of evidence about the depth to which sperm whales descend, presumably

in search of the squids. In April 1932, the cable repair ship *All America* was investigating an apparent break in the submarine cable between Balboa in the Canal Zone and Esmeraldas, Ecuador. The cable was brought to the surface off the coast of Colombia. Entangled in it was a dead 45-foot male sperm whale. The submarine cable was twisted around the lower jaw and was wrapped around one flipper the body and the caudal flukes. The cable was raised from a depth of 540 fathoms, or 3240 feet.

Some of the seals also appear to have discovered the hidden food reserves of the deep ocean. It has long been something of a mystery where and on what, the northern fur seals of the eastern Pacific feed during the winter which they spend off the coast of North America from California to Alaska. There is no evidence that they are feeding to any great extent on sardines, mackerel, or other commercially important fishes. Presumably four million seals could not compete with commercial fishermen for the same species without the fact being known. But there is some evidence on the diet of the fur seals, and it is highly significant. Their stomachs have yielded the bones of a species of fish that has never been seen alive. Indeed, not even its remains have been found anywhere except in the stomachs of seals. Ichthyologists say that this 'seal fish' belongs to group that typically inhabits very deep water off the edge of the continental shelf.

How either whales or seals endure the tremendous pressure changes involved in dives of several hundred fathoms is not definitely known. They are warm-blooded mammals like ourselves. Caisson disease, which is caused by the rapid accumulation of nitrogen bubbles in the blood with sudden release of pressure, kills human divers if they are brought up rapidly from depths of 200 feet or so. Yet, according to the testimony of whalers, a baleen whale, when harpooned, can dive straight down to a depth of half a mile, as measured by the amount of line carried out. From these depths, where it has sustained a pressure of half a ton on every inch of body it returns lmost immediately to the surface. The most plausible explanation is that, unlike the diver who has air pumped to him while he is under water the whale has in its body only the limited supply it carries down, and does not have enough nitrogen in its blood to do serious harm. The plain truth is, however that we really do not know since it is obviously impossible to confine living whale and experiment on it, and almost as difficult to dissect a dead one satisfactorily

At first thought it seems paradox that creatures of such great fragility as the glass sponge and the jellyfish can live under the conditions of immense pressure that prevail in deep water For creatures at home in the deep sea, however the saving

is that the pressure inside their tissues is the same as that out, and as long as this balance is preserved, they are no inconvenienced by a pressure of a ton or so than we are ordinary atmospheric pressure. And most abyssal creatures, must be remembered, live out their whole lives in a com tively restricted zone, and are never required to adj selves to extreme changes of pressure.

But of course there are exceptions, and the real sea life in relation to great pressure is not the animal that l its whole life on the bottom, bearing a pressure of perhaps or six tons, but those that regularly move up and d hundreds or thousands of feet of vertical change. The shrimps and other planktonic creatures that descend into water during the day are examples. Fish that possess air b ders, on the other hand, are vitally affected by abrupt of pressure, as anyone knows who has seen a trawler's raised from a hundred fathoms. Apart from the accident of ing captured in a net and hauled up through waters of rap diminishing pressures, fish may sometimes wander out of zone to which they are adjusted and find themselves unable return. Perhaps in their pursuit of food they roam upward the ceiling of the zone that is theirs, and beyond whose ble boundary they may not stray without meeting alien inhospitable conditions. Moving from layer to layer of dri as they feed, they may pass beyond the bou n the lessened pressure of these upper waters the gas within the air bladder expands. The fish becomes lighter more buoyant. Perhaps he tries to fight his way down again, posing the upward lift with all the power of his muscles. If does not succeed, he 'falls' to the surface, injured and for the abrupt release of pressure from without causes sion and rupture of the tissues.

The compression of the sea under its own weight is relati ly slight, and there is no basis for the old and picturesque bel that, at the deeper levels, the water resists the downward age of objects from the surface. According to this belief, si ing ships, the bodies of drowned men, and presumably t bodies of the larger sea animals not consumed by hungry scavengers, never reach the bottom, but come to rest at some level determined by the relation of their own weight to the compression of the water there to drift forever. The fact is that anything will continue to sink as long as its specific gravity is greater than that of the surrounding water and all large bodies descend, in a matter of a few days, to the ocean floor. As testimony to this fact, we bring up from the deepest ocean basins the teeth of sharks and the hard ear bones of whales.

Nevertheless the weight of sea water—the pressing down of

miles of water upon all the underlying layers—does have a certain effect upon the water itself. If this downward compression could suddenly be relaxed by some miraculous suspension of natural laws, the sea level would rise about 93 feet all over the world. This would shift the Atlantic coastline of the United States westward a hundred miles or more and alter other familiar geographic outlines all over the world.

Immense pressure, then, is one of the governing conditions of life in the deep sea, darkness is another. The unrelieved darkness of the deep waters has produced weird and incredible modifications of the abyssal fauna. It is a blackness so divorced from the world of the sunlight that probably only the few men who have seen it with their own eyes can visualize it. We know that light fades out rapidly with descent below the surface. The red rays are gone at the end of the first 200 or 300 feet, and with them all the orange and yellow warmth of the sun. Then the greens fade out, and at 1000 feet only a deep, dark, brilliant blue is left. In very clear waters the violet rays of the spectrum may penetrate another thousand feet. Beyond this is only the blackness of the deep sea.

In a curious way the colors of marine animals tend to be related to the zone in which they live. Fishes of the surface waters, like the mackerel and herring, often are blue or green; so are the floats of the Portuguese men-of-war and the azure-tinted wings of the swimming snails. Down below the diatom meadows and the drifting sargassum weed, where the water becomes ever more deeply, brilliantly blue, many creatures are crystal clear. Their glassy, ghostly forms blend with their surroundings and make it easier for them to elude the ever-present, ever-hungry enemy. Such are the transparent hordes of the arrow-worms or glassworms, the comb jellies, and the larvae of many fishes.

At a thousand feet, and on down to the very end of the sun's rays, silvery fishes are common, and many others are red, drab brown, or black. Pteropods are a dark violet. Arrowworms, whose relatives in the upper layers are colorless, are here a deep red. Jellyfish medusae, which above would be transparent, at a depth of 1000 feet are a deep brown.

At depths greater than 1500 feet, all the fishes are black, deep violet, or brown, but the prawns wear amazing hues of red, scarlet, and purple. Why, no one can say. Since all the red rays are strained out of the water far above this depth, the scarlet raiment of these creatures can only look black to their neighbors.

The deep sea has its stars, and perhaps here and there an eerie and transient equivalent of moonlight, for the mysteric phenomenon of luminescence is displayed by perhaps

all the fishes that live in dimly lit or darkened waters, and many of the lower forms as well. Many fishes carry lumi- torches that can be turned on or off at will, presumably help them find or pursue their prey. Others have rows of lights c their bodies, in patterns that vary from species to species may be a sort of recognition mark or badge by which bearer can be known as friend or enemy. The deep-sea ejects a spurt of fluid that becomes a luminous cloud, the terpart of the 'ink' of his shallow-water relative.

Down beyond the reach of even the longest and strongest the sun's rays, the eyes of fishes become enlarged, as though make the most of any chance illumination of whatever sort, they may become telescopic, large of lens, and protruding. deep-sea fishes, hunting always in dark waters, the eyes tend lose the 'cones' or color-perceiving cells of the retina, and increase the 'rods,' which perceive dim light. Exactly t modification is seen on land among the strictly prowlers which, like abyssal fish, never see the sunlight.

In their world of darkness, it would seem likely that some the animals might have become blind, as has happened to cave fauna. So, indeed, many of them have, compensating the lack of eyes with marvelously developed feelers and l slender fins and processes with which they grope their way so many blind men with canes, their whole knowledge friends, enemies, or food coming to them through the sense touch.

The last traces of plant life are left behind in the thin layer of water for no plant can live below about 600 feet – in very clear water and few find enough sunlight for manufacturing activities below 200 feet. Since no animal make its own food, the creatures of the deeper waters live strange, almost parasitic existence of utter dependence on upper layers. These hungry carnivores prey fiercely and lessly upon each other yet the whole community is ultimate dependent upon the slow rain of descending food particles above. The components of this never-ending rain are the dead and dying plants and animals from the surface, or from one of the intermediate layers. For each of the horizontal zones or communities of the sea that lie, in tier after tier between the surface and the sea bottom, the food supply is different and in general poorer than for the layer above. There is a hint of the fierce and uncompromising competition for food in the saber-toothed jaws of some of the small, dragonlike fishes of the deeper waters, in the immense mouths and in the elastic and dis- tensible bodies that make it possible for a fish to swallow an- other several times its size, enjoying swift repletion after a long fast.

Pressure, darkness, and—we should have added only a few years ago—silence, are the conditions of life in the deep sea. But we know now that the conception of the sea as a silent place is wholly false. Wide experience with hydrophones and other listening devices for the detection of submarines has proved that, around the shore lines of much of the world, there is the extraordinary uproar produced by fishes, shrimps, porpoises and probably other forms not yet identified. There has been little investigation as yet of sound in the deep, offshore areas, but when the crew of the *Atlantis* lowered a hydrophone into deep water off Bermuda, they recorded strange mewing sounds, shrieks, and ghostly moans, the sources of which have not been traced. But fish of shallower zones have been captured and confined in aquaria, where their voices have been recorded for comparison with sounds heard at sea, and in many cases satisfactory identification can be made.

During the Second World War the hydrophone network set up by the United States Navy to protect the entrance to Chesapeake Bay was temporarily made useless when, in the spring of 1942, the speakers at the surface began to give forth, every evening, a sound described as being like 'a pneumatic drill tearing up pavement. The extraneous noises that came over the hydrophones completely masked the sounds of the passage of ships. Eventually it was discovered that the sounds were the voices of fish known as croakers, which in the spring move into Chesapeake Bay from their offshore wintering grounds. As soon as the noise had been identified and analyzed, it was possible to screen it out with an electric filter so that once more only the sounds of ships came through the speakers.

Later in the same year a chorus of croakers was discovered off the pier of the Scripps Institution at La Jolla. Every year from May until late September the evening chorus begins about sunset, and "increases gradually to a steady uproar of harsh froggy croaks, with a background of soft drumming. This continues unabated for two to three hours and finally tapers off to individual outbursts at rare intervals. Several species of croakers isolated in aquaria gave sounds similar to the 'froggy' croaks, but the authors of the soft background drumming—presumably another species of croaker—have not yet been discovered.

One of the most extraordinarily widespread sounds of the undersea is the crackling, sizzling sound, like dry twigs burning or fat frying, heard near beds of the snapping shrimp. This is a small, round shrimp about half an inch in diameter, with one very large claw which it uses to stun its prey. The shrimp are forever clicking the two joints of this claw together and it is the thousands of clicks that collectively produce the noise known

seizing every advantage that makes possible the survival of living protoplasm in a world only a little less hostile than the reaches of interplanetary space.

## 5 Hidden Lands

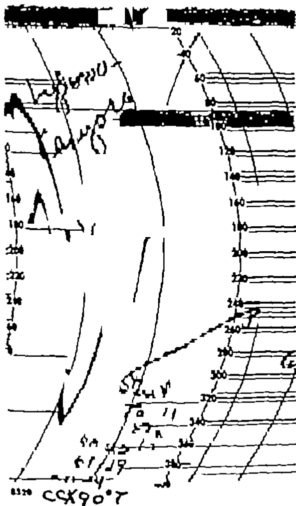
*Sand-strewn caverns cool and deep,*
*Where the winds are all asleep*

MATTHEW ARNOLD

THE FIRST European ever to sail across the wide Pacific was curious about the hidden worlds beneath his ship. Between two coral islands of St. Paul and Los Tiburones in the T Archipelago Magellan ordered his sounding line to be l It was the conventional line used by explorers of the day more than 200 fathoms long. It did not touch bottom, Magellan declared that he was over the deepest part of ocean. Of course he was completely mistaken, but the occasion was none the less historic. It was the first time in the history of the world that a navigator had attempted to sound the of the open ocean.

Three centuries later in the year 1839 Sir James Clark R set out from England in command of two ships with names dark foreboding, the *Erebus* and the *Terror* bound for the most navigable limits of the Antarctic Ocean. As he on his course he tried repeatedly to obtain soundings, but f for lack of a proper line. Finally he had one constructed board, of 'three thousand six hundred fathoms, or rather than four miles in length. On the 3rd of January in 27 26′ S., longitude 17 29′ W the weather and all other circumstances being propitious, we succeeded in obtaining soundings with two thousand four hundred and twenty-five fathoms of line, a depression of the bed of the ocean beneath its surface very little short of the elevation of Mount Blanc above it. This was the first successful abyssal sounding.

But taking soundings in the deep ocean was, and long remained, a laborious and time-consuming task, and knowledge of the undersea topography lagged considerably behind our acquaintance with the landscape of the near side of the moon. Over the years, methods were improved. For the heavy hemp line used by Ross, Maury of the United States Navy substituted a strong twine, and in 1870 Lord Kelvin used piano wire. Even with improved gear a deep-water sounding required several hours or sometimes an entire day By 1854 when Maury collected all available records, only 180 deep soundings were avail-




*The U.S.S.* ALBATROSS III *traced this profile of Lydonia Canyon where it cuts across the outer edge of George Bank.*

able from the Atlantic, and by the time that modern echo ing was developed, the total that had been taken from all ocean basins of the world was only about 15,000. This ly one sounding for an area of 6000 square miles.

Now hundreds of vessels are equipped with sonic instruments that trace a continuous profile of the bottom neath the moving ship (although only a few can obtain profile at depths greater than 2000 fathoms). Soundings are accum lating much faster than they can be plotted on the charts. Li tle by little, like the details of a huge map being filled in by artist, the hidden contours of the ocean are emerging. But, with this recent progress, it will be years before an accu and detailed relief map of the ocean basins can be construc.

The general bottom topography is, however well Once we have passed the tide lines, the three great provinces of ocean are the continental shelves, the slopes, and the floor of the deep sea. Each of these regions is different from the others as an arctic tundra from a range of Rocky Mountains.

The continental shelf is of the sea, yet of all regions of ocean it is most lik the land. Sunlight penetrates to all but deepest parts. Plants drift in the waters above it, seaweeds c to its rocks and sway to the passage of the waves. Famil —unlike the weird monsters of the abyss—move over like herds of cattle. Much of its substance is derived from land—the sand and the rock fragments and the rich ried by running water to the sea and gently deposited on shelf. Its submerged valleys and hills, in appropriate parts of th world, have been carved by glaciers into a topography m. like the northern landscapes we know and the terrain is strewn with rocks and gravel deposited by the moving ice sheets. Indeed many parts (or perhaps all) of the shelf have been dry land in the geologic past, for a comparatively slight fall of sea level has sufficed, time and again, to expose it to wind and sun and rain. The Grand Banks of Newfoundland rose above the ancient seas and were submerged again. The Dogger Bank of the North Sea shelf was once a forested land inhabited by prehistoric beasts; now its 'forests' are seaweeds and its 'beasts' are fishes.

Of all parts of the sea, the continental shelves are perhaps most directly important to man as a source of material things. The great fisheries of the world, with only a few exceptions, are confined to the relatively shallow waters over the continental shelves. Seaweeds are gathered from their submerged plains to make scores of substances used in foods, drugs, and articles of commerce. As the petroleum reserves left on continental areas by ancient seas become depleted, petroleum geologists look

more and more to the oil that may lie, as yet unmapped and unexploited, under these bordering lands of the sea.

The shelves begin at the tidelines and extend seaward as gently sloping plains. The 100-fathom contour used to be taken as the boundary between the continental shelf and the slope; now it is customary to place the division wherever the gentle declivity of the shelf changes abruptly to a steeper descent toward abyssal depths. The world over the average depth at which this change occurs is about 72 fathoms; the greatest depth of any shelf is probably 200 to 300 fathoms.

Nowhere off the Pacific coast of the United States is the continental shelf much more than 20 miles wide—a narrowness characteristic of coasts bordered by young mountains perhaps still in the process of formation. On the American east coast, however, north of Cape Hatteras the shelf is as much as 150 miles wide. But at Hatteras and off southern Florida it is merely the narrowest of thresholds to the sea. Here its scant development seems to be related to the press of that great and rapidly flowing river-in-the-sea, the Gulf Stream, which at these places swings close inshore.

The widest shelves in all the world are those bordering the Arctic. The Barents Sea shelf is 750 miles across. It is also relatively deep, lying for the most part 100 to 200 fathoms below the surface, as though its floor had sagged and been downwarped under the load of glacial ice. It is scored by deep troughs between which banks and islands rise—further evidence of the work of the ice. The deepest shelves surround the Antarctic continent, where soundings in many areas show depths of several hundred fathoms near the coast and continuing out across the shelf.

Once beyond the edge of the shelf, as we visualize the steeper declivities of the continental slope, we begin to feel the mystery and the alien quality of the deep sea—the gathering darkness, the growing pressure, the starkness of seascape in which all plant life has been left behind and there are only the unrelieved contours of rock and clay, of mud and sand.

Biologically the world of the continental slope, like that of the abyss, is a world of animals—a world of carnivores where each creature preys upon another. For no plants live here, and the only ones that drift down from above are the dead husks of the flora of the sunlit waters. Most of the slopes are below the zone of surface wave action, yet the moving water masses of the ocean currents press against them in their coastwise passage; the pulse of the tide beats against them; they feel the surge of the deep, internal waves.

Geographically, the slopes are the most imposing all the surface of the earth. They are the walls of the

basins. They are the farthermost bounds of the continents, true place of beginning of the sea. The slopes are the and highest escarpments found anywhere on the earth, average height is 12,000 feet, but in some places they reach immense height of 30,000 feet. No continental mount has so great a difference of elevation between its foothills its peaks.

Nor is the grandeur of slope topography confined to ness and height. The slopes are the site of one of the most terious features of the sea. These are the submarine can with their steep cliffs and winding valleys cutting back into walls of the continents. The canyons have now been found so many parts of the world that when soundings have taken in presently unexplored areas we shall probably find they are of world-wide occurrence. Geologists say that some the canyons were f rmed well within the most recent divi of geologic time, the Cenozoic, most of them probably the Pleistocene, million years ago or less. But how and what they were carved, no one can say Their origin is one the most hotly disputed problems of the ocean.

Only the fact that the canyons are deeply hidden in the ness of the sea (many extending mile or more below sea level) prevents them from being classed with the most spectacular scenery The comparison with the Grand C yon of the Colorado is irresistible. Like river-cut land sea canyons are deep and winding valleys, V-shaped in section, their walls sloping down at a steep angle to a floor The location of many of the largest ones suggests a connection with some of the great rivers of the earth of time. Hudson Canyon, one of the largest on the A is separated by only a shallow sill from a long valley th wanders for more than a hundred miles across the continental shelf originating at the entrance of New York Harbor and the estuary of the Hudson River There are large canyons off the Congo the Indus, the Ganges, the Columbia, the São Francisco and the Mississippi, according to Francis Shepard, one of the principal students of the canyon problem. Monterey Canyon in California, Professor Shepard points out, is located off an old mouth of the Salinas River the Cap Breton Canyon in France appears to have no relation to an existing river but actually lies off an old fifteenth-century mouth of the Adour River

Their shape and apparent relation to existing rivers have led Shepard to suggest that the submarine canyons were cut by rivers at some time when their gorges were above sea level. The relative youth of the canyons seems to relate them to some happenings in the world of the Ice Age. It is generally agreed that sea level was lowered during the existence of the great glaciers

for water was withdrawn from the sea and frozen in the ice sheet. But most geologists say that the sea was lowered only a few hundred feet—not the mile that would be necessary to account for the canyons. According to one theory there were heavy submarine mud flows during the times when the glaciers were advancing and sea level fell the lowest, mud stirred up by waves poured down the continental slopes and scoured out the canyons. Since none of the present evidence is conclusive, however we simply do not know how the canyons came into being, and their mystery remains.

The floor of the deep ocean basins is probably as old as the sea itself. In all the hundreds of millions of years that have intervened since the formation of the abyss, these deeper depressions have never, as far as we can learn, been drained of their covering waters. While the bordering shelves of the continents have known, in alternating geologic ages, now the surge of waves and again the eroding tools of rain and wind and frost, always the abyss has lain under the all-enveloping cover of miles-deep water

But this does not mean that the contours of the abyss have remained unchanged since the day of its creation. The floor of the sea, like the stuff of the continents, is a thin crust over the molten center of the earth. It is here thrust up into folds and wrinkles as the interior cools by imperceptible degrees and shrinks away from its covering layer there it falls away into deep trenches in answer to the stresses and strains of crustal adjustment; and again it pushes up into the conelike shapes of undersea mountains as volcanoes boil upward from fissures in the crust.

Until very recent years, it has been the fashion of geographers and oceanographers to speak of the floor of the deep sea as vast and comparatively level plain. The existence of certain topographic features was recognized, as, for example, the Atlantic Ridge and number of very deep depressions like the Mindanao Trench off the Philippines. But these were considered to be rather exceptional interruptions of a flat floor that otherwise showed little relief.

This legend of the flatness of the ocean floor was thoroughly destroyed by the Swedish Deep-Sea Expedition, which sailed from Göteborg in the summer of 1947 and spent the following 15 months exploring the bed of the ocean. While the Swedish *Albatross* was crossing the Atlantic in the direction of the Panama Canal, the scientists aboard were astonished by the extreme ruggedness of the ocean floor Rarely did their fathometers reveal more than a few consecutive miles of level plain. Instead the bottom profile rose and fell in curious steps constructed on a G rgantuan scale, half mile to several miles wide. In

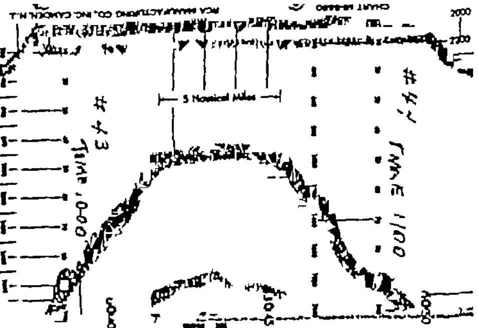
Pacific, the uneven bottom contours made it difficult to many of the oceanographic instruments. More than tube was left behind, probably lodged in some crevasse.

One of the exceptions to a hilly or mountainous the Indian Ocean, where, southeast of Ceylon, the A ran for several hundred miles across a level plain. Attempts take bottom samples from this plain had little success, for corers were broken repeatedly suggesting that the bottom hardened lava and that the whole vast plateau might been formed by the outpourings of submarine volcanoes stupendous scale. Perhaps this lava plain under the Ocean is an undersea counterpart of the great basaltic pl in the eastern part of the State of Washington, or of the plateau of India, built of basaltic rock 10,000 feet thick.

In parts of the Atlantic basin the Woods Hole C Institution's vessel *Atlantis* has found a flat plain occupy much of the ocean basin from Bermuda to the Atlantic R and also to the east of the Ridge. Only a series of knolls, ably of volcanic origin, interrupts the even contours of plains. These particular regions are so flat that it seems *must have remained largely undisturbed, receiving deposits* sediments over an immense period of time.

The deepest depressions on the floor of the sea occur not the centers of the oceanic basins as might be expected, but the continents. One of the deepest trenches of all, the danao, lies east of the Philippines and is an awesome pit in sea, six and a half miles deep. The Tuscarora Trench east Japan, nearly as deep, is one of a series of long, narrow that border the convex outer rim of a chain of islands lo the Bonins, the Marianas, and the Palaus. On the seaward side of the Aleutian Islands is another group of trenches. The greatest deeps of the Atlantic lie adjacent to the islands of the West Indies, and also below Cape Horn, where other curving chains of islands go out like stepping stones into the Southern Ocean. And again in the Indian Ocean the curving island arcs of the East Indies have their accompanying deeps.

Always there is this association of island arcs and deep trenches, and always the two occur only in areas of volcanic unrest. The pattern, it is now agreed, is associated with mountain making and the sharp adjustments of the sea floor that accompany it. On the concave side of the island arcs are rows of volcanoes. On the convex side there is a sharp down-bending of the ocean floor which results in the deep trenches with their broad V-shape. The two forces seem to be in a kind of uneasy balance the upward folding of the earth's crust to form mountains, and the thrusting down of the crust of the sea floor into




*This sea mount was discovered by the U.S. Coast and Geodetic Survey's* PATHFINDER *in the Gulf of Alaska. It rises 9600 feet from the ocean floor and is 857 fathoms below the surface*

the basaltic substance of the underlying layer Sometimes, it seems, the down-thrust mass of granite has shattered and risen again to form islands. Such is the supposed origin of Barbados in the West Indies and of Timor in the East Indies. Both have deep-sea deposits, as though they had once been part of the sea floor Yet this must be exceptional. In the words of the great geologist Daly

Another property of the earth is its ability to resist shearing pressures indefinitely The continents, overlooking the sea bottom, stubbornly refuse to creep thither The rock under the Pacific is strong enough to bear with no known limit, the huge stresses involved by the down-thrust of the at the Tonga Deep and by the erection of the 10 000- dome of lavas and other volcanic products represented in Island of Hawaii."*

The least known region of the ocean floor lies under the tic Sea. The physical difficulties of sounding here A permanent sheet of ice, as much as fifteen feet thick, the whole central basin and is impenetrable to ships. Peary several soundings in the course of his dash to the Pole by team in 1909 On one attempt a few miles from the Pole wire broke with 1500 fathoms out. In 1927 Sir Hubert Wi landed his plane on the ice 550 miles north of Point Barrow obtained a single echo sounding of 2975 fathoms, the d ever recorded from the Arctic Sea. Vessels deliberately into the ice (such as the Norwegian *Fram* and the Russ *Sedov* and *Sadko*) in order to drift with it across the basin obtained most of the depth records available for the centr parts. In 1937 and 1938 Russian scientists were landed the Pole and supplied by plane while they lived on the ice, drifting with it. These men took nearly a score of deep soundings.

The most daring plan for sounding the Arctic Sea was conceived by Wilkins, who actually set out in the submarine *Nautilus* in 1931 with the intention of traveling beneath the ice across the entire basin from Spitsbergen to Bering Strait. Mechanical failure of the diving equipment a few days after the *Nautilus* left Spitsbergen prevented the execution of the plan. By the middle 1940's, the total of soundings for deep arctic areas by all methods was only about 150 leaving most of the top of the world an unsounded sea whose contours can only be guessed. Soon after the close of the Second World War the United States Navy began tests of a new method of obtaining soundings through the ice, which may provide the key to the arctic riddle. One interesting speculation to be tested by soundings is that the mountain chain that bisects the Atlantic,

* From *The Changing World of the Ice Age* 1934 edition, Yale University Press, p. 116.

and has been supposed to reach its northern terminus at Iceland, may actually continue across the arctic basin to the coast of Russia. The belt of earthquake epicenters that follows the Atlantic Ridge seems to extend across the Arctic Sea, and where there are submarine earthquakes it is at least reasonable to guess that there may be mountainous topography

A new feature on recent maps of undersea relief—something never included before the 1940's—is a group of about 160 curious, flat-topped sea mounts between Hawaii and the Marianas. It happened that a Princeton University geologist, H. H. Hess, was in command of the U.S.S. *Cape Johnson* during two years of the wartime cruising of this vessel in the Pacific. Hess was immediately struck by the number of these undersea mountains that appeared on the fathogram of the vessel. Time after time, as the moving pen of the fathometer traced the depth contours it would abruptly begin to rise in an outline of a steep-sided sea mount, standing solitarily on the bed of the sea. Unlike a typical volcanic cone, all of the mounts have broad, flat tops, as though the peaks had been cut off and planed down by waves. But the summits of the sea mounts are anywhere from half a mile to a mile or more below the surface of the sea. How they acquired their flat-topped contours is a mystery perhaps as great as that of the submarine canyons.

Unlike the scattered sea mounts, the long ranges of undersea mountains have been marked on the charts for a good many years. The Atlantic Ridge was discovered about a century ago. The early surveys for the route of the trans-Atlantic cable gave the first hint of its existence. The German oceanographic vessel *Meteor* which crossed and recrossed the Atlantic during the 1920's, established the contours of much of the Ridge. The *Atlantis* of the Woods Hole Oceanographic Institution has spent several summers in an exhaustive study of the Ridge in the general vicinity of the Azores.

Now we can trace the outlines of this great mountain range, and dimly we begin to see the details of its hidden pe ks and valleys. The Ridge rises in mid-Atlantic near Iceland. From this far-northern latitude it runs south midw y between the continents, crosses the equator into the South Atlantic, and continues to about 50° south latitude where it turns sharply eastward under the tip of Africa and runs toward the Indian Ocean. Its general course closely parallels the coastlines of the bordering continents, even to the definite flexure at the equator between the hump of Brazil and the eastward-curving coast of Africa. To some people this curvature has suggested that the Ridge was once part of great continental mass, left behind in mid-ocean when, ccording to one theory the continents of North and South America drifted away from Europe

Africa. However recent work shows that on the floor of Atlantic there are thick masses of sediments which required hundreds of millions of years for their accumulation.

Throughout much of its 10 000-mile length, the A Ridge is a place of disturbed and uneasy movements of the ocean floor and the whole Ridge gives the impression thing formed by the interplay of great, opposing forces. From its western foothills across to where its slopes roll down into the eastern Atlantic basin, the range is about twice as wide as the Andes and several times the width of the Appalachians. Near the equator a deep gash cuts across it from east the Romanche Trench. This is the only point of co between the deep basins of the eastern and western Atlantic although among its higher peaks there are other lesser mountain passes.

The greater part of the Ridge is, of course, submerged. It central backbone rises some 5 000 to 10,000 feet above the floor but another mile of water lies above most of its Yet here and there a peak thrusts itself up out of the of deep water and pushes above the surface of the ocean. T are the islands of the mid-Atlantic. The highest peak of Ridge is Pico Island of the Azores. It rises 27 000 feet the ocean floor with only its upper 7,000 to 8 000 feet gent. The sharpest peaks of the Ridge are the cluster of known as the Rocks of St. Paul, near the equator The enti. cluster of half a dozen islets is not more than a quarter of mile across, and their rocky slopes drop off at so sheer an that water more than half a mile deep lies only a few feet shore. The sultry volcanic bulk of Ascension is another peak of the Atlantic Ridge· so are Tristan da Cunha, Gough, and Bouvet.

But most of the Ridge lies forever hidden from human eyes. Its contours have been made out only indirectly by the marvelous probings of sound waves bits of its substance have been brought up to us by corers and dredges; and some details of its landscape have been photographed with deep-sea cameras. With these aids our imaginations can picture the grandeur of the undersea mountains, with their sheer cliffs and rocky terraces, their deep valleys and towering peaks. If we are to compare the ocean's mountains with anything on the continents, we must think of terrestrial mountains far above the timber line, with their silent snow-filled valleys and their naked rocks swept by the winds. For the sea has an inverted 'timber line' or plant line, below which no vegetation can grow The slopes of the undersea mountains are far beyond the reach of the sun's rays, and there are only the bare rocks, and, in the valleys, the deep

drifts of sediments that have been silently piling up through the millions upon millions of years.

Neither the Pacific Ocean nor the Indian Ocean has any submerged mountains that compare in length with the Atlantic Ridge, but they have their smaller ranges. The Hawaiian Islands are the peaks of a mountain range that runs across the central Pacific basin for a distance of nearly 2000 miles. The Gilbert and Marshall islands stand on the shoulders of another mid-Pacific mountain chain. In the eastern Pacific, a broad plateau connects the coast of South America and the Tuamotu Islands in the mid-Pacific, and in the Indian Ocean a long ridge runs from India to Antarctica, for most of its length broader and deeper than the Atlantic Ridge.

One of the most fascinating fields for speculation is the age of the submarine mountains compared with that of past and present mountains of the continents. Looking back over the past ages of geologic time (page 14) we realize that mountains have been thrust up on the continents, to the accompaniment of volcanic outpourings and violent tremblings of the earth, only to crumble and wear away under the attacks of rain and frost and flood. What of the sea's mountains? Were they formed in the same way and do they too, begin to die as soon as they are born?

There are indications that the earth's crust is no more stable under sea than on land. Quite a fair proportion of the world's earthquakes are traced through seismographs to sources under the oceans, and, as we shall see later there are probably as many active volcanoes under water as on land. Apparently the Atlantic Ridge arose along a line of crustal shifting and rearrangement although its volcanic fires seem to be largely quiescent, it is at present the site of most of the earthquakes in the Atlantic area. Almost the whole continental rim of the Pacific basin is aquiver with earthquakes and fiery with volcanoes, some frequently active, some extinct, some merely sleeping centuries-long sleep between periods of explosive violence. From the high mountains that form an almost continuous border around the shores of the Pacific, the contours of the land slope abruptly down to very deep water The deep trenches that lie off the coast of South America, from Alaska along the Aleutian Islands and across to Japan, and southward off Japan and the Philippines give the impression of landscape in process of formation, of a zone of earth subject to great strains.

Yet the submarine mountains are earth nearest approach to the eternal hills of the poets. No sooner is continental mountain thrust up than all the forces of nature conspire to level it. A mountain of the deep sea, in the years of its maturity beyond the reach of the ordinary erosive forces. It gro

the ocean floor and may thrust volcanic peaks above the s
of the sea. These islands are attacked by the rains, and in time
the young mountain is brought down within reach of the
In the tumult of the sea's attack it sinks again beneath
face. Eventually the peak is worn down below the push
and drag of even the heaviest of storm waves. Here, in the tw
light of the sea, in the calm of deep water the mountain i
secure from further attack. Here it is likely to remain almost
unchanged, perhaps throughout the life of the earth.

Because of this virtual immortality the oldest o
tains must be infinitely older than any of the ranges left
land. Professor Hess, who discovered the sea mounts of the c
tral Pacific, suggested that these drowned ancient islands
have been formed before the Cambrian period, or
between 500 million and 1 billion years ago. This wo d
them perhaps of an age with the continental mountains of
Laurentian upheaval. But the sea mounts have changed little
at all, comparing in elevation with modern terrestrial
like the Jungfrau, Mt. Etna, or Mt. Hood while of the m
tains of the Laurentian period scarcely a trace remains.
Pacific sea mounts, according to this theory must have
of substantial age when the Appalachians were thrust up
million years ago they stood almost unchanged while the
lachians wore down to mere wrinkles on the earth's face.
sea mounts were old, 60 million years ago when the Alps
the Himalayas, the Rockies and the Andes, rose to their ma
tic heights. Yet it is probable that they will be standing
changed in the deep sea when these, too, shall have crumbl
away to dust.

As the hidden lands beneath the sea become better known,
there recurs gain and again the query can the submerged
masses of the undersea mountains be linked with the famed
'lost continents'? Shadowy and insubstantial as are the accounts
of all such legendary lands—the fabled Lemuria of the Indian
Ocean, St. Brendan's Island, the lost Atlantis—they persistently
recur like some deeply rooted racial memory in the folklore of
many parts of the world.

Best known is Atlantis, which according to Plato's account
was a large island or continent beyond the Pillars of Hercules.
Atlantis was the home of a warlike people ruled by powerful
kings who made frequent attacks upon the mainlands of Africa
and Europe, brought much of Libya under their power roamed
the Mediterranean coast of Europe, and finally attacked
Athens. However 'with great earthquakes and inundations, in
a single day and one fatal night, all who had been
[against Greece] were swallowed up. The island of Atlantis dis-
appeared beneath the sea. Since that time the sea in these

quarters has become unnavigable; vessels cannot pass there because of the sands which extend over the site of the buried isle.

The Atlantis legend has lived on through the centuries. As men became bold enough to sail out on the Atlantic, to cross it, and later to investigate its depths, they speculated about the location of the lost land. Various Atlantic islands have been said to be the remains of a land mass once more extensive. The lonely wave-washed Rocks of St. Paul, perhaps more often than any other have been identified as the remains of Atlantis. During the past century as the extent of the Atlantic Ridge became better known, speculations were often centered upon this great mass, far below the surface of the ocean.

Unfortunately for these picturesque imaginings, if the Ridge was ever exposed, it must have been at a time long before there were men to populate such an Atlantis. Some of the cores taken from the Ridge show a continuous series of sediments typical of open oceans, far from land, running back to a period some 60 million years ago. And man, even the most primitive type, has appeared only within the past million years or so.

Like other legends deeply rooted in folklore, the Atlantis story may have in it an element of truth. In the shadowy beginnings of human life on earth, primitive men here and there must have had knowledge of the sinking of an island or a peninsula, perhaps not with the dramatic suddenness attributed to Atlantis, but well within the time one man could observe. The witnesses of such a happening would have described it to their neighbors and children, and so the legend of a sinking continent might have been born.

Such a lost land lies today beneath the waters of the North Sea. Only a few scores of thousands of years ago, the Dogger Bank was dry land, but now the fishermen drag their nets over this famed fishing ground, catching cod and hake and flounders among its drowned tree trunks.

During the Pleistocene, when immense quantities of water were withdrawn from the ocean and locked up in the glaciers, the floor of the North Sea emerged and for a time became land. It was a low wet land, covered with peat bogs; then little by little the forests from the neighboring high lands must have moved in, for there were willows and birches growing among the mosses and ferns. Animals moved down from the mainland and became established on this land recently won from the sea. There were bears and wolves and hyenas, the wild ox, [illegible] the woolly rhinoceros, and the mammoth. Primitive men moved through the forests, carrying crude stone instruments; they stalked deer and other game and with their [illegible] the roots of the damp forest.

Then as the glaciers began to retreat and floods from melting ice poured into the sea and raised its level, this became an island. Probably the men escaped to the m before the intervening channel had become too wide their stone implements behind. But most of the animals mained, perforce, and little by little their island food became more and more scarce, but there was Finally the sea covered the island, claiming the land its life.

As for the men who escaped, perhaps in their primitive they communicated this story to other men, who passed it to others through the ages, until it became fixed in the of the race.

None of these facts were part of recorded history until generation go, European fishermen moved out into of the North Sea and began to trawl on the Dogger made out the contours of an irregular plateau nearly as as Denmark, lying about 60 feet under water but sloping abruptly at its edges into much deeper water. Their trawls mediately began to bring up a great many things not any ordinary fishing bank. There were loose masses of which the fishermen christened moorlog. There were bones, and, although the fishermen could not identify they seemed to belong to large land mammals. All of objects damaged the nets and hindered fishing, so when possible the fishermen dragged them off the bank and sent tumbling into deep water. But they brought back some of bones, some of the moorlog and fragments of trees, and crude stone implements, these specimens were turned scientists to identify. In this strange debris of the fishi the scientists recognized a whole Pleistocene fauna and flora and the artifacts of Stone Age man. And remembering how once the North Sea had been dry land, they reconstructed the story of Dogger Bank, the lost island.

# 6 The Long Snowfall

*A deep and tremulous earth-poetry*
LLEWELYN POWYS

EVERY PART of earth or air or sea has an atmosphere peculiarly its own, a quality or characteristic that sets it apart from all others. When I think of the floor of the deep sea, the single, overwhelming fact that possesses my imagination is the accumulation of sediments. I see always the steady, unremitting, downward drift of materials from above, flake upon flake, layer

son layer—a drift that has continued for hundreds of millions of years, that will go on as long as there are seas and continents.

For the sediments are the materials of the most stupendous 'snowfall' the earth has ever seen. It began when the first rains fell on the barren rocks and set in motion the forces of erosion. It was accelerated when living creatures developed in the surface waters and the discarded little shells of lime or silica that had encased them in life began to drift downward to the bottom. Silently, endlessly, with the deliberation of earth processes that can afford to be slow because they have so much time for completion, the accumulation of the sediments has proceeded. So little in a year or in a human lifetime, but so enormous an amount in the life of earth and sea.

The rains, the eroding away of the earth, the rush of sediment-laden waters have continued, with varying pulse and tempo, throughout all of geologic time. In addition to the silt load of every river that finds its way to the sea, there are other materials that compose the sediments. Volcanic dust, blown perhaps half way around the earth in the upper atmosphere, comes eventually to rest on the ocean, drifts in the currents, becomes waterlogged, and sinks. Sands from coastal deserts are carried seaward on offshore winds, fall to the sea, and sink. Gravel, pebbles, small boulders, and shells are carried by icebergs and drift ice, to be released to the water when the ice melts. Fragments of iron, nickel, and other meteoric debris that enter the earth's atmosphere over the sea—these, too, become flakes of the great snowfall. But most widely distributed of all are the billions upon billions of tiny shells and skeletons, the limy or siliceous remains of all the minute creatures that once lived in the upper waters.

The sediments are a sort of epic poem of the earth. When we are wise enough, perhaps we can read in them all of past history. For all is written here. In the nature of the materials that compose them and in the arrangement of their successive layers the sediments reflect all that has happened in the waters above them and on the surrounding lands. The dramatic and the catastrophic in earth history have left their trace in the sediments—the outpourings of volcanoes, the advance and retreat of the ice, the searing aridity of desert lands, the sweeping destruction of floods.

The book of the sediments has been opened only within the lifetime of the present generation of scientists, with the most exciting progress in collecting and deciphering samples made since 1945. Early oceanographers could scrape up surface layers of sediment from the sea bottom with dredges. But what was needed was an instrument, operated on the apple corer that could be driven vertically into the

remove a long sample or core in which the order of the ent layers was undisturbed. Such an instrument was by Dr C. S. Piggot in 1935 and with the aid of this obtained a series of cores across the deep Atlantic from foundland to Ireland. These cores averaged about 10 feet A piston core sampler developed by the Swedish o pher Kullenberg about 10 years later now takes cores 70 feet long. The rate of sedimentation in the parts of the ocean is not definitely known, but it is very certainly such a sample represents millions of years history

Another ingenious method for studying the sediment been used by Professor W Maurice Ewing of Columbia versity and the Woods Hole Oceanographic Institution. sor Ewing found that he could measure the thickness of carpeting layer of sediments that overlies the rock of the floor by exploding depth charges and recording their one echo is received from the top of the sediment layer apparent bottom of the sea) another from the 'bottom be the bottom or the true rock floor The carrying and use explosives at sea is hazardous and cannot be attempted by vessels, but this method was used by the Swedish *Albatross* well as by the *Atlantis* in its exploration of the Atlantic Ewing on the *Atlantis* also used a seismic refraction by which sound waves are made to travel horizontally the rock layers of the ocean floor providing the nature of the rock.

Before these techniques were developed, we could only at the thickness of the sediment blanket over the floor of the sea. We might have expected the amount to be vast, If we thought back through the ages of gentle, unending fall—one sand grain at a time, one fragile shell after another here a shark's tooth, there a meteorite fragment—but the whole continuing persistently relentlessly endlessly It is, of course, a process similar to that which has built up the layers of rock that help to make our mountains, for they too were once soft sediments under the shallow seas that have overflowed the continents from to time. eventually became consoli seas retreated again, gave the thi of sedimentary rocks—l car tilted, compressed, and and we know that, in places tr of fee

the open Atlantic basin showed sediment layers as much as 12,000 feet thick.

If more than two miles of sediments have been deposited on the floor of the Atlantic, an interesting question arises has the rock floor sagged a corresponding distance under the terrific weight of the sediments? Geologists hold conflicting opinions. The recently discovered Pacific sea mounts may offer one piece of evidence that it has. If they are, as their discoverer called them, drowned ancient islands, then they may have reached their present stand a mile or so below sea level through the sinking of the ocean floor Hess believed the islands had been formed so long ago that coral animals had not yet evolved, otherwise the corals would presumably have settled on the flat, planed surfaces of the sea mounts and built them up as fast as their bases sank. In any event, it is hard to see how they could have been worn down so far below 'wave base unless the crust of the earth sagged under its load.

One thing seems probable—the sediments have been unevenly distributed both in place and time. In contrast to the 12,000-foot thickness found in parts of the Atlantic, the Swedish oceanographers never found sediments thicker than 1000 feet in the Pacific or in the Indian Ocean. Perhaps a deep layer of lava, from ancient submarine eruptions on a stupendous scale, underlies the upper layer of the sediments in these places and intercepts the sound waves.

Interesting variations in the thickness of the sediment layer on the Atlantic Ridge and the approaches to the Ridge from the American side were reported by Ewing. As the bottom contours became less even and began to slope up into the foothills of the Ridge, the sediments thickened, as though piling up into mammoth drifts 1000 to 2000 feet deep against the slopes of the hills. Farther up in the mountains of the Ridge, where there are many level terraces from a few to a score of miles wide, the sediments were even deeper measuring up to 3000 feet. But along the backbone of the Ridge, on the steep slopes and peaks and pinnacles, the bare rock emerged, swept clean of sediments.

Reflecting on these differences in thickness and distribution, our minds return inevitably to the simile of the long snowfall. We may think of the abyssal snowstorm in terms of bleak and blizzard-ridden arctic tundra. Long days of storm visit this place, when driving snow fills the air then lull comes in the blizzard, and the snowfall is light. In the snowfall of the sediments, also, there is an alternation of light and heavy falls. The heavy falls correspond to the periods of mountain building on the continents, when the lands are lifted high and the rain rushes down their slopes, carrying mud and rock fragments to the sea the light falls mark the lulls between the mountain-building period

remove a long sample or 'core' in which the order of the different layers was undisturbed. Such an instrument was invented by Dr C. S. Piggot in 1935 and with the aid of this 'gun' he obtained a series of cores across the deep Atlantic from Newfoundland to Ireland. These cores averaged about 10 feet long. A piston core sampler developed by the Swedish ... pher Kullenberg about 10 years later now takes undisturbed cores 70 feet long. The rate of sedimentation in the different parts of the ocean is not definitely known, but it is very slow; certainly such a sample represents millions of years of geo... history.

Another ingenious method for studying the sediments has been used by Professor W. Maurice Ewing of Columbia University and the Woods Hole Oceanographic Institution. Professor Ewing found that he could measure the thickness of the carpeting layer of sediments that overlies the rock of the ocean floor by exploding depth charges and recording their echoes; one echo is received from the top of the sediment layer (the apparent bottom of the sea), another from the 'bottom below the bottom' or the true rock floor. The carrying and use of explosives at sea is hazardous and cannot be attempted by all vessels, but this method was used by the Swedish *Albatross* as well as by the *Atlantis* in its exploration of the Atlantic. Ewing on the *Atlantis* also used a seismic refraction technique by which sound waves are made to travel horizontally through the rock layers of the ocean floor providing information about the nature of the rock.

Before these techniques were developed, we could only guess at the thickness of the sediment blanket over the floor of the sea. We might have expected the amount to be vast, if we thought back through the ages of gentle, unending fall—one sand grain at a time, one fragile shell after another, here a shark's tooth, there a meteorite fragment—but the whole continuing persistently, relentlessly, endlessly. It is, of course, a process similar to that which has built up the layers of rock that help to make our mountains, for they, too, were once soft sediments under the shallow seas that have overflowed the continents from time to time. The sediments eventually became consolidated and cemented and, as the seas retreated again, gave the continents their thick, covering layers of sedimentary rocks—layers which we can see uplifted, tilted, compressed, and broken by the vast earth movements. And we know that in places the sedimentary rocks are many thousands of feet thick. Yet most people felt a shock of surprise and wonder when Hans Pettersson, leader of the Swedish Deep Sea Expedition, announced that the *Albatross* measurements taken in

surface zones where the living radiolarians occur most numerously.

Two other kinds of organic sediments are named for the creatures whose remains compose them. Diatoms, the microscopic plant life of the sea, flourish most abundantly in cold waters. There is a broad belt of diatom ooze on the floor of the Antarctic Ocean, outside the zone of glacial debris dropped by the ice pack. There is another across the North Pacific, along the chain of great deeps that run from Alaska to Japan. Both are zones where nutrient-laden water wells up from the depths, sustaining a rich growth of plants. The diatoms, like the radiolaria, are encased in siliceous coverings—small, boxlike cases of varied shape and meticulously etched design.

Then, in relatively shallow parts of the open Atlantic, there are patches of ooze composed of the remains of delicate swimming snails, called pteropods. These winged mollusks, possessing transparent shells of great beauty, are here and there incredibly abundant. Pteropod ooze is the characteristic bottom deposit in the vicinity of Bermuda, and a large patch occurs in the South Atlantic.

Mysterious and eerie are the immense areas, especially in the North Pacific, carpeted with a soft, red sediment in which there are no organic remains except sharks' teeth and the ear bones of whales. This red clay occurs at great depths. Perhaps all the materials of the other sediments are dissolved before they can reach this zone of immense pressures and glacial cold.

The reading of the story contained in the sediments has only begun. When more cores are collected and examined we shall certainly decipher many exciting chapters. Geologists have pointed out that a series of cores from the Mediterranean might settle several controversial problems concerning the history of the ocean and of the lands around the Mediterranean basin. For example, somewhere in the layers of sediment under this sea there must be evidence, in a sharply defined layer of sand, of the time when the deserts of the Sahara were formed and the hot, dry winds began to skim off the shifting surface layers and carry them seaward. Long cores recently obtained in the western Mediterranean off Algeria have given a record of volcanic activity extending back through thousands of years, and including great prehistoric eruptions of which we know nothing.

The Atlantic cores taken more than a decade ago by Piggot from the cable ship *Lord Kelvin* have been thoroughly studied by geologists. From their analysis it is possible to look back into the past 10,000 years or so and to sense the pulse of the earth's climatic rhythms; for the cores were composed of layers of cold-water globigerina faunas (and hence glacial stages) alternating with globigerina ooze characteristic

warmer waters. From the clues furnished by these cores we can visualize interglacial stages when there were periods of mild climates, with warm water overlying the sea bottom warmth-loving creatures living in the ocean. Between periods the sea grew chill. Clouds gathered, the snows fell, on the North American continent the great ice sheets grew the ice mountains moved out to the coast. The glaciers the sea along a wide front, there they produced thousand. The slow-moving, majestic processions of the passed out to sea, and because of the coldness of much of t earth they penetrated farther south than any but stray bergs today. When finally they melted, they relinquished their loads silt and sand and gravel and rock fragments that had frozen into their under surfaces as they made their way over the land. And so a layer of glacial sediment came overlie the normal globigerina ooze, and the record of an Age was inscribed.

Then the sea grew warmer again, the glaciers melted and treated, and once more the warmer-water species of ina lived in the sea—lived and died and drifted down to bui another layer of globigerina ooze, this time over the clays a gravels from the glaciers. And the record of warmth and mil ness was again written in the sediments. From the Piggot it has been possible to reconstruct four different periods of th advance of the ice, separated by periods of warm climate.

It is interesting to think that even now in our own lif the flakes of a new snow storm are falling, falling, one by out there on the ocean floor The billions of Globigerina drifting down, writing their unequivocal record that this, present world, is on the whole a world of mild and tempera climate. Who will read their record, ten thousand years from now?

# 7 The Birth of an Island

*Many a green isle needs must be*
*In the deep wide sea*

SHELLEY

MILLIONS of years ago, a volcano built a mountain on the floor of the Atlantic. In eruption after eruption, it pushed up a great pile of volcanic rock, until it had accumulated a mass a hundred miles across at its base, reaching upward toward the surface of the sea. Finally its cone emerged as an island with an area of about 200 square miles. Thousands of years passed, and thousands of thousands. Eventually the waves of

cut down the cone and reduced it to a shoal—all of it, that is, but a small fragment which remained above water. This fragment we know as Bermuda.

With variations, the life story of Bermuda has been repeated y almost every one of the islands that interrupt the watery expanses of the oceans far from land. For these isolated islands i the sea are fundamentally different from the continents. The major land masses and the ocean basins are today much as they ave been throughout the greater part of geologic time. But slands are ephemeral, created today destroyed tomorrow With few exceptions, they are the result of the violent, explosive, earth-shaking eruptions of submarine volcanoes, working perhaps for millions of years to achieve their end. It is one of the paradoxes in the ways of earth and sea that a process seemingly so destructive, so catastrophic in nature, can result in an act of creation.

Islands have always fascinated the human mind. Perhaps it is the instinctive response of man, the land animal, welcoming a brief intrusion of earth in the vast, overwhelming expanse of sea. Here in a great ocean basin, a thousand miles from the nearest continent, with miles of water under our vessel we come upon an island. Our imaginations can follow its slopes down through darkening waters to where it rests on the sea floor We wonder why and how it arose here in the midst of the ocean.

The birth of a volcanic island is an event marked by prolonged and violent travail the forces of the earth striving to create, and all the forces of the sea opposing. The sea floor where an island begins, is probably nowhere more than about fifty miles thick—a thin covering over the vast bulk of the earth. In it are deep cracks and fissures, the results of unequal cooling and shrinkage in past ages. Along such lines of weakness the molten lava from the earth's interior presses up and finally bursts forth into the sea. But submarine volcano is different from a terrestrial eruption, where the lava, molten rocks, gases, and other ejecta are hurled into the air through an open crater Here on the bottom of the ocean the volcano has resisting it all the weight of the ocean water above it. Despite the immense pressure of, it may be, two or three miles of sea water the new volcanic cone builds upward toward the surface in flow after flow of lava. Once within reach of the waves, its soft ash and tuff are violently attacked, and for a long period the potential island may remain a shoal, unable to emerge But, eventually in new eruptions, the cone is pushed up into the air and a rampart against the ttacks of the waves is built of lava.

Navigators' charts are marked with numerous,

covered submarine mountains. Many of these are the merged remnants of the islands of a geologic yesterday The same charts show islands that emerged from the sea at least fifty million years ago, and others that arose within our own memory Among the undersea mountains marked on may be the islands of tomorrow which at this moment forming, unseen, on the floor of the ocean and are growing up ward toward its surface.

For the sea is by no means done with submarine eruptions they occur fairly commonly sometimes detected only by in struments, sometimes obvious to the most casual observer Ships in volcanic zones may suddenly find themselves in lently disturbed water There are heavy discharges of The sea appears to bubble or boil in a furious turbulence. Fo tains spring from its surface. Floating up from the deep h places of the actual eruption come the bodies of fishes other deep-sea creatures, and quantities of volcanic ash pumice.

One of the youngest of the large volcanic islands of the wor is Ascension in the South Atlantic. During the Second W War the American airmen sang

*If we don t find Asc nsion*
*Our wives will get pension*

this island being the only piece of dry land between the hur of Brazil and the bulge of Africa. It is a forbidding mass of cir ders, in which the vents of no less than forty extinct v can be counted. It has not always been so barren, for its s have yielded the fossil remains of trees. What happened to forests no one knows the first men to explore the island, abou the year 1500 found it treeless, and today it has no natural greenness except on its highest peak, known as Green Moun tain.

In modern times we have never seen the birth of an island as large as Ascension. But now and then there is a report of a small island appearing where none was before. Perhaps a month, a year five years later the island has disappeared into the sea again. These are the little, stillborn islands, doomed to only a brief emergence above the sea.

About 1830 such an island suddenly appeared in the Mediter ranean between Sicily and the coast of Africa, rising from 100-fathom depths after there had been signs of volcanic activity in the area. It was little more than a black cinder pile, perhaps 200 feet high. Waves, wind, and rain attacked it. Its soft and porous materials were easily eroded its ubstance was rapidly eaten away and it sank beneath the sea. Now it is a shoal, marked on the charts as Graham s Reef.

Falcon Island, the tip of a volcano projecting above the Pacific nearly two thousand miles east of Australia, suddenly disappeared in 1913. Thirteen years later, after violent eruptions in the vicinity, it as suddenly rose again above the surface and remained as a physical bit of the British Empire until 1949. Then it was reported by the Colonial Under Secretary to be missing again.

Almost from the moment of its creation, a volcanic island is foredoomed to destruction. It has in itself the seeds of its own dissolution, for new explosions, or landslides of the soft soil, may violently accelerate its disintegration. Whether the destruction of an island comes quickly or only after long ages of geologic time may also depend on external forces: the rains that wear away the loftiest of land mountains, the sea, and even man himself.

South Trinidad, or in the Portuguese spelling, 'Ilha Trindade,' is an example of an island that has been sculptured into bizarre forms through centuries of weathering—an island in which the signs of dissolution are clearly apparent. This group of volcanic peaks lies in the open Atlantic, about a thousand miles north-east of Rio de Janeiro. E. F. Knight wrote in 1907 that Trinidad 'is rotten throughout, its substance has been disintegrated by volcanic fires and by the action of water, so that it is everywhere tumbling to pieces.' During an interval of nine years between Knight's visits, a whole mountainside had collapsed in a great landslide of broken rocks and volcanic debris.

Sometimes the disintegration takes abrupt and violent form. The greatest explosion of historic time was the literal evisceration of the island of Krakatoa. In 1680 there had been a premonitory eruption of this small island in Sunda Strait, between Java and Sumatra in Indonesia. Two hundred years later there had been a series of earthquakes. In the spring of 1883, smoke and steam began to ascend from fissures in the volcanic cone. The ground became noticeably warm, and warning rumblings and hissings came from the volcano. Then, on 27 August, Krakatoa literally exploded. In an appalling series of eruptions that lasted two days, the whole northern half of the cone was carried away. The sudden inrush of ocean water added the fury of superheated steam to the caldron. When the inferno [illegible] white-hot lava, molten rock, steam, and smoke had finally [illegible] sided, the island that had stood 1400 feet above the sea [illegible] become [illegible] cavity a thousand feet below sea level. Only [illegible] one edge of the former crater did a remnant of the [illegible] remain.

Krakatoa, in its destruction, became known [illegible] world. The eruption gave rise to a hundred-[illegible]

wiped out villages along the Strait and killed people by tens o thousands. The wave was felt on the shores of the Indi Ocean and at Cape Horn rounding the Cape into the Atlantic, it sped northward and retained its identity even as far as English Channel. The sound of the explosions was heard in Philippine Islands, in Australia, and on the Island of Madag car nearly 3000 miles away And clouds of volcanic dust, pulverized rock that had been torn from the heart of Krakatoa, ascended into the stratosphere and were carried around globe to give rise to a series of spectacular sunsets in ever country of the world for nearly a year

Although Krakatoa's dramatic passing was the most viol eruption that modern man has witnessed, Krakatoa itself to have been the product of an even greater one. There is dence that an immense volcano once stood where the waters Sunda Strait now lie. In some remote period a titanic exp blew it away leaving only its base represented by a broken of islands. The largest of these was Krakatoa, which in its demise, carried way what was left of the original crater ring. But in 1929 a new volcanic island arose in this place—A Krakatoa, Child of Krakatoa.

Subterranean fires and deep unrest disturb the whole occupied by the Aleutians. The islands themselves are the of a thousand-mile chain of undersea mountains, of whi( volcanic action was the chief architect. The geologic structure of the ridge is little known, but it rises abruptly from oceanic depths of about a mile on one side and two miles on the other Apparently this narrow ridge indicates a deep fracture of the earth's crust. On many of the islands volcanoes are now active, or only temporarily quiescent. In the short history of modern navigation in this region, it has often happened that a new island has been reported but perhaps only the following year could not be found.

The small island of Bogoslof since it was first discovered in 1796, has altered its shape and position several times and has even disappeared completely only to emerge again. The original island was a mass of black rock, sculptured into fantastic, towering shapes. Explorers and sealers coming upon it in the fog were reminded of a castle and named it Castle Rock. At the present time there remain only one or two pinnacles of the castle, a long spit of black rocks where sea lions haul out, and a cluster of higher rocks resounding with the cries of thousands of sea birds. Each time the parent volcano erupts, as it has done at least half a dozen times since men have been observing it, new masses of steaming rocks emerge from heated waters, some to reach heights of several hundred feet before they are destroyed in fresh explosions. Each new cone

that appears is, as described by the volcanologist Jaggar 'the live crust, equivalent to a crater of a great submarine heap of lava six thousand feet high, piled above the floor of the Bering Sea where the Aleutian mountains fall off to the deep sea.'

One of the few exceptions to the almost universal rule that oceanic islands have a volcanic origin seems to be the remarkable and fascinating group of islets known as the Rocks of St. Paul. Lying in the open Atlantic between Brazil and Africa, St. Paul's Rocks are an obstruction thrust up from the floor of the ocean into the midst of the racing Equatorial Current, a mass against which the seas, which have rolled a thousand miles unhindered, break in sudden violence. The entire cluster of rocks covers not more than a quarter of a mile, running in curved line like a horseshoe. The highest rock is not more than sixty feet above the sea spray wets it to the summit. Abruptly the rocks dip under water and slope steeply down into great depths. Geologists since the time of Darwin have puzzled over the origin of these black, wave-washed islets. Most of them agree that they are composed of material lik that of the sea floor itself. In some remote period, inconceivable stresses in the earth crust must have pushed a solid rock mass upward more than two miles.

So bare and desolate that not even a lichen grows on them, St. Paul's Rocks would seem one of the most unpromising places in the world to look for a spider spinning its web in arachnidan hope of snaring passing insects. Yet Darwin found spiders when he visited the Rocks in 1833 and forty years later the naturalists of H.M.S. *Challenger* also reported them, busy at their web-spinning A few insects are there, too some as parasites on the sea birds, three species of which nest on the Rocks. One of the insects is a small brown moth that lives on feathers. This very nearly completes the inventory of the inhabitants of St. Paul' Rocks, except for the grotesque crabs that swarm over the islets, living chiefly on the flying fish brought by the birds to their young.

St. Paul's Rocks are not alone in having an extraordinary assortment of inhabitants, for the faunas and floras of oceanic islands are amazingly different from those of the continents. The pattern of island lif is peculiar and significant. Aside from forms recently introduced by man, islands remote from the continents are never inhabited by any land mammals, except sometimes the one mammal that has learned to fly—the bat. There are never any frogs, salamanders, or other amphibians. Of reptiles, there ma be few snakes, lizards, and turtles, but the more remote the island from a major land mass, the fewer reptiles there are and the really isolated islands have none. There are usually a few species of land birds, some

some spiders. So remote an island as Tristan da Cunha in the South Atlantic, 1500 miles from the nearest continent, has no land animals but these three species of land birds, a few insects and several small snails.

With so selective a list, it is hard to see how as some biol gists believe, the islands could have been colonized by migratio across land bridges, even if there were good evidence for the existence of the bridges. The very animals missing from the islands are the ones that would have had to come dry-shod, o the hypothetical bridges. The plants and animals that we on oceanic islands, on the other hand, are the ones that have come by wind or water As an alternative, then, we suppose that the stocking of the islands has been accomp by the strangest migration in earth's history—a migration began long before man ppeared on the earth and is still con tinuing, a migration that seems more like a series of cosmic cidents than an orderly process of nature.

We can only guess how long after its emergence from sea an oceanic island may lie uninhabited. Certainly in original state it is a land bare, harsh, and repelling beyo human experience. No living thing moves over the slopes of l olcanic hills, no plants cover its naked lava fields. But little by little, riding on the winds, drifting on the currents, or r on logs, floating brush, or trees, the plants and animals are to colonize it arrive from the distant continents.

So deliberate, so unhurried, so inexorable are the ways of nature that the stocking of an island may require thousands or millions of years. It may be that no more than half a dozen times in all these eons does a particular form, such as a tor toise make a successful landing upon its shores. To wonder impatiently why man is not a constant witness of such arrivals is to fail to understand the majestic pace of the process.

Yet we have occasional glimpses of the method. Natural rafts of uprooted trees and matted vegetation have frequently been seen adrift at sea, more than a thousand miles off the mouths of such great tropical rivers as the Congo, the *Ganges*, the Amazon, and the Orinoco. Such rafts could easily carry an assortment of insect, reptile, or mollusk passengers. Some of the involuntary passengers might be able to withstand long weeks at sea, others would die during the first stages of the journey Probably the ones best adapted for travel by raft are the wood-boring insects, which, of all the insect tribe, are most commonly found on oceanic islands. The poorest raft travelers must be the mammals. But even a mammal might cover short interisland distances. A few days after the explosion of Kraka-toa, a small monkey was rescued from some drifting timber in

Sunda Strait. She had been terribly burned, but survived the experience.

No less than the water the winds and the air currents play their part in bringing inhabitants to the islands. The upper atmosphere, even during the ages before man entered it in his machines, was a place of congested traffic. Thousands of feet above the earth, the air is crowded with living creatures, drifting, flying, gliding, ballooning, or involuntarily swirling along on the high winds. Discovery of this rich aerial plankton had to wait until man himself had found means to make physical invasion of these regions. With special nets and traps, scientists have now collected from the upper atmosphere many of the forms that inhabit oceanic islands. Spiders, whose almost invariable presence on these islands is a fascinating problem, have been captured nearly three miles above the earth's surface. Airmen have passed through great numbers of the white, silken filaments of spiders' 'parachutes' at heights of two or three miles. At altitudes of 6,000 to 16,000 feet, and with wind velocities reaching 45 miles an hour many living insects have been taken. At such heights and on such strong winds, they might well have been carried hundreds of miles. Seeds have been collected at altitudes up to 5,000 feet. Among those commonly taken are members of the Composite family especially the so-called 'thistle-down' typical of oceanic islands.

An interesting point about transport of living plants and animals by wind is the fact that in the upper layers of the earth's atmosphere the winds do not necessarily blow in the same direction as at the earth's surface. The trade winds are notably shallow so that a man standing on the cliffs of St. Helena, a thousand feet above the sea, is above the wind, which blows with great force below him. Once drawn into the upper air insects, seeds, and the like can easily be carried in a direction contrary to that of the winds prevailing at island level.

The wide-ranging birds that visit islands of the ocean in migration may also have a good deal to do with the distribution of plants, and perhaps even of some insects and minute land shells. From ball of mud taken from a bird's plumage, Charles Darwin raised 82 separate plants, belonging t distinct species! Many plant seeds have hooks or prickles, ideal for attachment to feathers. Such birds as the Pacific golden plover which annually flies from the mainland of Alaska to the Hawaiian Islands and even beyond, probably figure in many riddles of plant distribution.

The catastrophe of Krakatoa gave naturalists perfect opportunity to observe the colonization of an island. With most of the island itself destroyed, and the remnant covered with deep layer of lava and ash that remained hot for weeks, K

toa after the explosive eruptions of 1883 was, from a biol standpoint, a new volcanic island. As soon as it was possi to visit it, scientists searched for signs of life, although it hard to imagine how any living thing could have survived. a single plant or animal could be found. It was not until months after the eruption that the naturalist Cotteau was to report 'I only discovered one microscopic spider—only This strange pioneer of the renovation was busy spinning web Since there were no insects on the island, the web-spi ning of the bold little spider was presumably in vain, and, for a few blades of grass, practically nothing lived on Krak for a quarter of a century Then the colonists began to a few mammals in 1908 a number of birds, lizards, snakes various mollusks, insects, and earthworms. Ninety cent of Krakatoa's new inhabitants, Dutch scientists fo were forms that could have arrived by air

Isolated from the great mass of life on the continents, no opportunity for the crossbreeding that tends to preserve average and to eliminate the new and unusual, island life developed in a remarkable manner On these remote bits earth, nature has excelled in the creation of strange and wo ful forms. As though to prove her incredible versatility al every island has developed species that are endemic—that they are peculiar to it alone and are duplicated nowhere el on earth.

It was from the pages of earth's history written on the lava fields of the Galapagos that young Charles Darwin got his first inkling of the great truths of the origin of species. Observing the strange plants and animals—giant tortoises, black, amazing lizards that hunted their food in the surf, sea lions, birds in extraordinary variety—Darwin was struck by their vague similarity to mainland species of South and Central America, yet was haunted by the differences, differences that distinguish them not only from the mainland species but from those on other islands of the archipelago. Years later he was to write in reminiscence 'Both in space and time, we seem to be brought somewhat near to that great fact—that mystery of mysteries—the first appearance of new beings on earth.

Of the 'new beings' evolved on islands, some of the most striking examples have been birds. In some remote age before there were men, a small pigeonlike bird found its way to the island of Mauritius, in the Indian Ocean. By processes of change at which we can only guess, this bird lost the power of flight, developed short, stout legs, and grew larger until it reached the size of a modern turkey Such was the origin of the fabulous dodo which did not long survive the advent of man on Mauritius. New Zealand was the sole home of the

moas. One species of these ostrichlike birds stood twelve feet high. Moas had roamed New Zealand from the early part of the Tertiary; those that remained when the Maoris arrived soon died out.

Other island forms besides the dodo and the moas have tended to become large. Perhaps the Galapagos tortoise became a giant after its arrival on the islands, although fossil remains on the continents cast doubt on this. The loss of wing use and even of the wings themselves (the moas had none) are common results of insular life. Insects on small, wind-swept islands tend to lose the power of flight—those that retain it are in danger of being blown out to sea. The Galapagos Islands have a flightless cormorant. There have been at least fourteen species of flightless rails on the islands of the Pacific alone.

One of the most interesting and engaging characteristics of island species is their extraordinary tameness—a lack of sophistication in dealings with the human race, which even the bitter teachings of experience do not quickly alter. When Robert Cushman Murphy visited the island of South Trinidad in 1913 with a party from the brig *Daisy*, terns alighted on the heads of the men in the whaleboat and peered inquiringly into their faces. Albatrosses on Laysan, whose habits include wonderful ceremonial dances, allowed naturalists to walk among their colonies and responded with a grave bow to similar polite greetings from the visitors. When the British ornithologist David Lack visited the Galapagos Islands, a century after Darwin, he found that the hawks allowed themselves to be touched, and the flycatchers tried to remove hair from the heads of the men for nesting material. It is a curious pleasure, he wrote, "to have the birds of the wilderness settling upon one's shoulders, and the pleasure could be much less rare were man less destructive."

But man, unhappily, has written one of his blackest records as a destroyer on the oceanic islands. He has seldom set foot on an island that he has not brought about disastrous changes. He has destroyed environments by cutting, clearing, and burning; he has brought with him as a chance associate the nefarious rat; and almost invariably he has turned loose upon the islands a whole Noah's Ark of goats, hogs, cattle, dogs, cats, and other nonnative animals as well as plants. Upon species after species of island life the black night of extinction has fallen.

In all the world of living things, it is doubtful whether there is a more delicately balanced relationship than that of island life to its environment. This environment is a remarkably uniform one. In the midst of a great ocean, ruled by currents and winds that rarely shift their course, climate changes little. There are few natural enemies, perhaps none at all. The ha

for existence that is the normal lot of continental life is so on the islands. When this gentle pattern of life is abr changed, the island creatures have little ability to make the justments necessary for survival.

Ernst Mayr tells of a steamer wrecked off Lord Howe I east of Australia in 1918. Its rats swam ashore. In two they had so nearly exterminated the native birds that an i wrote, 'This paradise of birds has become a wilderness, the quietness of death reigns where all was melody

On Tristan da Cunha almost all of the unique land birds had evolved there in the course of the ages were by hogs and rats. The native fauna of the island of Tahiti is l ing ground against the horde of alien species that man has troduced. The Hawaiian Islands, which have lost their na plants and animals faster than almost any other area in world, are a classic example of the results of interfering wi natural balances. Certain relations of animal to plant, and plant to sod, had grown up through the centuries. When came in and rudely disturbed the balance, he set off a series of chain reactions.

Vancouver brought cattle and goats to the Hawaiian I lands, and the resulting damage to forests and other vege was enormous. Many plant introductions were as bad. A known as the pamakani was brought in many years ago, cording to report, by a Captain Makee for his beaut 1 on the island of Maui. The pamakani, which has light, wi borne seeds, quickly escaped from the captain's gardens, n the pasture lands on Maui, and proceeded to hop from island to island. The CCC boys were at one time put to work to clear it out of the Honouliuli Forest Reserve, but as fast as they destroyed it, the seeds of new plants arrived on the wind. Lantana was another plant brought in as an ornamental species. Now it covers thousands of acres with a thorny scrambling growth—despite large sums of money spent to import parasitic insects to control it.

There was once a society in Hawaii for the special purpose of introducing exotic birds. Today when you go to the islands you see, instead of the exquisite native birds that greeted Captain Cook, mynas from India, cardinals from the United States or Brazil, doves from Asia, weavers from Australia, skylarks from Europe, and titmice from Japan. Most of the original bird life has been wiped out, and to find its fugitive remnants you would have to search assiduously in the most remote hills.

Some of the island species have, at best, the most tenuous hold on life. The Laysan teal is found nowhere in the but on the one small island of Laysan. Even on this occurs only on one end, where there is a seepage

water. Probably the total population of this species does not exceed fifty individuals. Destruction of the small swampy bit of land that is its home, or the introduction of a hostile or competing species, could easily snap the slender thread of life.

Most of man's habitual tampering with nature's balance by introducing exotic species has been done in ignorance of the fatal chain of events that would follow. But in modern times, at least, we might profit by history. About the year 1513 the Portuguese introduced goats onto the recently discovered island of St. Helena, which had developed a magnificent forest of gumwood, ebony and brazilwood. By 1560 or thereabouts, the goats had so multiplied that they wandered over the island by the thousand, in flocks a mile long. They trampled the young trees and ate the seedlings. By this time the colonists had begun to cut and burn the forests, so that it is hard to say whether men or goats were the more responsible for the destruction. But of the result there was no doubt. By the early 1800's the forests were gone, and the naturalist Alfred Wallace later described this once beautiful, forest-clad volcanic island as a 'rocky desert,' in which the remnants of the original flora persisted only in the most inaccessible peaks and crater ridges.

When the astronomer Halley visited the islands of the Atlantic about 1700, he put a few goats ashore on South Trinidad. This time, without the further aid of man, the work of deforestation proceeded so rapidly that it was nearly completed within the century. Today Trinidad's slopes are the place of a ghost forest, strewn with the fallen and decaying trunks of long-dead trees; its soft volcanic soils, no longer held by the interlacing roots, are sliding away into the sea.

One of the most interesting of the Pacific islands was Laysan, a tiny scrap of soil which is a far outrider of the Hawaiian chain. It once supported a forest of sandalwood and fanleaf palms and had five land birds, all peculiar to Laysan alone. One of them was the Laysan rail, a charming, gnomelike creature no more than six inches high, with wings that seemed too small (and were never used as wings) and feet that seemed too large, and a voice like distant, tinkling bells. About 1887 the captain of a visiting ship moved some of the rails to Midway, about 300 miles to the west, establishing a second colony. It seemed a fortunate move, for soon thereafter rabbits were introduced on Laysan. Within a quarter of a century the rabbits had killed off the vegetation of the tiny island, reduced it to a sandy desert, and all but exterminated themselves. As for the rails, the devastation of their island was fatal, and the last rail died about 1924.

Perhaps the Laysan colony could later have been restored from the Midway group had not tragedy struck there also.

ing the war in the Pacific, rats went ashore to island land from ships and landing crafts. They invaded Midway 1943 The adult rails were slaughtered. The eggs were eat and the young birds killed. The world's last Laysan rail seen in 1944

The tragedy of the oceanic islands lies in the uniqueness, irreplaceability of the species they have developed by the processes of the ages. In a reasonable world men would treated these islands as precious possessions, as natural tuns filled with beautiful and curious works of creation, va ble beyond price because nowhere in the world are they cated. W H. Hudson s lament for the birds of the A- pampas might even more truly have been spoken of the lands 'The beautiful has vanished and returns not.

## 8 The Shape of Ancient Seas

*Till the slow sea rise and th sheer cliff crumble*
*Till terrace and meadow the de p gulf drink.*

SWINBURNE

WE LIVE in an age of rising seas. Along all the coasts of United States a continuing rise of sea level has been percep on the tide gauges of the Coast and Geodetic Survey s 1930. For the thousand-mile stretch from Massachusetts to Florida, and on the coast of the Gulf of Mexico, the rise amounted to about a third of a foot between 1930 and 1948. The water is also rising (but more slowly) along the Pacific shores. These records of the tide gauges do not include the transient advances and retreats of the water caused by winds and storms, but signify a steady continuing advance of the sea upon the land.

This evidence of a rising sea is an interesting and even an exciting thing because it is rare that in the short span of human life, we can actually observe and measure the progress of one of the great earth rhythms. What is happening is nothing new Over the long span of geologic time the ocean waters have come in over North America many times and have again retreated into their basins. For the boundary between sea and land is the most fleeting and transitory feature of the earth, and the sea is forever repeating its encroachments upon the continents in its flood, reluctant in its ebb, moving in a rhythm mysterious and infinitely deliberate.

Now once again the ocean is overfull. It is spilling over the rims of its basins. It fills the shallow seas that border the con-

tinents, like the Barents, Bering, and China seas. Here and there it has advanced into the interior and lies in such inland seas as Hudson Bay the St. Lawrence embayment, the Baltic, and the Sunda Sea. On the Atlantic coast of the United States the mouths of many rivers, like the Hudson and the Susquehanna, have been drowned by the advancing flood the old, submerged channels are hidden under bays like the Chesapeake and the Delaware.

The advance noted so clearly on the tide gauges may be part of a long rise that began thousands of years ago—perhaps when the glaciers of the most recent Ice Age began to melt. But it is only within recent decades that there have been instruments to measure it in any part of the world. Even now the gauges are few and scattered, considering the world as a whole. Because of the scarcity of world records, it is not known whether the rise observed in the United States since 1930 is being duplicated on all other continents.

Where and when the ocean will halt its present advance and begin again its slow retreat into its basin, no one can say If the rise over the continent of North America should amount to a hundred feet (and there is more than enough water now frozen in land ice to provide such a rise) most of the Atlantic seaboard, with its cities and towns, would be submerged. The surf would break against the foothills of the Appalachians. The coastal plain of the Gulf of Mexico would lie under water: the lower part of the Mississippi Valley would be submerged.

If, however the rise should be as much as 600 feet, large areas in the eastern half of the continent would disappear under the waters. The Appalachians would become a chain of mountainous islands. The Gulf of Mexico would creep north, finally meeting in mid-continent with the flood that had entered from the Atlantic into the Great Lakes, through the valley of the St. Lawrence. Much of northern Canada would be covered by water from the Arctic Ocean and Hudson Bay

All of this would seem to us extraordinary and catastrophic, but the truth is that North America and most other continents have known even more extensive invasion by the sea than the one we have just imagined. Probably the greatest submergence in the history of the earth took place in the Cretaceous period, about 100 million years go. Then the ocean waters advanced upon North America from the north, south, and east, finally forming an inland sea about 1000 miles wide that extended from the Arctic to the Gulf of Mexico, and then spread eastward to cover the coastal plain from the Gulf to New Jersey At the height of the Cretaceous flood about half of North America was submerged. All over the world the seas rose They covered most of the British Isles, except for scattered ou.

of ancient rocks. In southern Europe only the old, rocky lands stood above the sea, which intruded in long bays and even into the central highlands of the continent. The moved into Africa and laid down deposits of sandstones weathering of these rocks provided the desert sands of Sahara. From a drowned Sweden, an inland sea flowed Russia, covered the Caspian Sea, and extended to the layas. Parts of India were submerged, and of Australia, and Siberia. On the South American continent, the area later the Andes were to rise was covered by sea.

With variations of extent and detail, these events repeated again and again. The very ancient Ordovician some 400 million years ago, submerged more than half of America, leaving only a few large islands marking the lands of the continent, and a scattering of smaller ones rising of the inland sea. The marine transgressions of Devonian Silurian time were almost as extensive. But each time the tern of invasion was a little different, and it is doubtful there is any part of the continent that at some time has not at the bottom of one of these shallow seas.

You do not have to travel to find the sea, for the traces of ancient stands are everywhere about. Though you may be thousand miles inland, you can easily find reminders that w reconstruct for the eye and ear of the mind the processions its ghostly waves and the roar of its surf, far back in time. on a mountain top in Pennsylvania, I have sat on rocks whitened limestone, fashioned of the shells of billions billions of minute sea creatures. Once they had lived and di in an arm of the ocean that overlay this place, and their remains had settled to the bottom. Then, after eons of time they had become compacted into rock and the sea had receded after yet more eons the rock had been uplifted by bucklings of the earth's crust and now it formed the backbone of a long mountain range.

Far in the interior of the Florida Everglades I have wondered at the feeling of the sea that came to me—wondered until I realized that here were the same flatness, the same immense spaces, the same dominance of the sky and its moving, changing clouds wondered until I remembered that the hard rocky floor on which I stood, its flatness interrupted by upthrust masses of jagged coral rock had been only recently constructed by the busy architects of the coral reefs under a warm sea. Now the rock is thinly covered with grass and water but everywhere is the feeling that the land has formed only the thinnest veneer over the underlying platform of the sea, that at any moment the process might be reversed and the sea reclaim its own.

So in all lands we may sense the former presence of the sea.

There are outcroppings of marine limestone in the Himalayas, now at an elevation of 20,000 feet. These rocks are reminders of a warm, clear sea that lay over southern Europe and northern Africa and extended into southwestern Asia. This was some 50 million years ago. Immense numbers of a large protozoan known as nummulites swarmed in this sea and each, in death, contributed to the building of a thick layer of nummulitic limestone. Eons later the ancient Egyptians were to carve their Sphinx from mass of this rock, other deposits of the same stone they quarried to obtain material to build their pyramids.

The famous white cliffs of Dover are composed of chalk deposited by the seas of the Cretaceous period, during that great inundation we have spoken of. The chalk extends from Ireland through Denmark and Germany and forms its thickest beds in south Russia. In consists of shells of those minute sea creatures called foraminifera, the shells being cemented together with a fine-textured deposit of calcium carbonate. In contrast to the foraminiferal ooze that covers large areas of ocean bottom at moderate depths, the chalk seems to be a shallow-water deposit, but it is so pure in texture that the surrounding lands must have been low deserts, from which little material was carried seaward. Grains of wind-borne quartz sand, which frequently occur in the chalk, support this view. At certain levels the chalk contains nodules of flint. Stone Age men mined the flint for weapons and tools and also used this relic of the Cretaceous sea to light their fires.

Many of the natural wonders of the earth owe their existence to the fact that once the sea crept over the land, laid down its deposits of sediments, and then withdrew. There is Mammoth C ve in Kentucky for example, where one may wander through miles of underground passages and enter rooms with ceilings 250 feet overhead. Caves and passageways have been dissolved by ground water out f an immense thickness of limestone deposited by a Paleozoic sea. I the same way the story of Niagara Falls goes back to Silurian time, when a vast embayment of the Arctic Sea crept southward over the continent. Its waters were clear for the borderlands were low and little sediment or silt was carried into the inland sea. It deposited large bed of the hard rock called dolomit and in time they formed long escarpment near the present border between Canada nd the United States. Millions of years later floods of water released from melting glaciers poured over this cliff cutting w y the soft shales that underlay the dolomite, and causing mass fter mass of the undercut rock to break awa In this fashion Niagara Falls and its gorge were

Some of these inland seas were immense and i

tures of their world, although all of them were shallow pared with the central basin where, since earliest time, the of the ocean waters have resided. Some may have been as as 600 feet deep, about the same as the depths over the edge of the continental shelf. No one knows the pattern of currents, but often they must have carried the warmth of tropics into far northern lands. During the Cretaceous for example, breadfruit, cinnamon, laurel, and fig trees grew Greenland. When the continents were reduced to groups of lands there must have been few places that possessed a tinental type of climate with its harsh extremes of heat cold mild oceanic climates must rather have been the

Geologists say that each of the grander divisions of earth tory consists of three phases in the first the continents high, erosion is active, and the seas are largely confined to the basins in the second the continents are lowest and the have invaded them broadly in the third the continents begun once more to rise. According to the late Cha ert, who devoted much of his distinguished career as a geologi to mapping the ancient seas and lands "Today we are livi in the beginning of a new cycle, when the continents are highest, and scenically grandest. The oceans, however begun another invasion upon North America.

What brings the ocean out of its deep basins, where it been contained for eons of time to invade the lands? Probably there has always been not one alone, but a combination of causes.

The mobility of the earth's crust is inseparably linked with the changing relations of sea and land—the warping upward or downward of that surprisingly plastic substance which forms the outer covering of the earth. The crustal movements affect both land and sea bottom but are most marked near the continental margins. They may involve one or both shores of an ocean, one or all coasts of a continent. They proceed in a slow and mysterious cycle, one phase of which may require millions of years for its completion. Each downward movement of the continental crust is accompanied by a slow flooding of the land by the sea, each upward buckling by the retreat of the water

But the movements of the earth's crust are not alone responsible for the invading seas. There are other important causes. Certainly one of them is the displacement of ocean water by land sediments. Every grain of sand or silt carried out by the rivers and deposited at sea displaces a corresponding amount of water Disintegration of the land and the seaward freighting of its substance have gone on without interruption since the beginning of geologic time. It might be thought that the sea level would have been rising continuously but the matter is

not so simple. As they lose substance the continents tend to rise higher like a ship relieved of part of its cargo. The ocean floor to which the sediments are transferred, sags under its load. The exact combination of all these conditions that will result in a rising ocean level is a very complex matter not fully recognized or predicted.

Then there is the growth of the great submarine volcanoes, which build up immense lava cones on the floor of the ocean. Some geologists believe these may have an important effect on the changing level of the sea. The bulk of some of these volcanoes is impressive. Bermuda is one of the smallest, but its volume beneath the surface is about 2500 cubic miles. The Hawaiian chain of volcanic islands extends for nearly 2000 miles across the Pacific and contains several islands of great size; its total displacement of water must be tremendous. Perhaps it is more than coincidence that this chain arose in Cretaceous time, when the greatest flood the world has ever seen advanced upon the continents.

For the past million years, all other causes of marine transgressions have been dwarfed by the dominating role of the glaciers. The Pleistocene period was marked by alternating advances and retreats of a great ice sheet. Four times the ice caps formed and grew deep over the land, pressing southward into the valleys and over the plains. And four times the ice melted and shrank and withdrew from the lands it had covered. We live now in the last stages of this fourth withdrawal. About half the ice formed in the last Pleistocene glaciation remains in the ice caps of Greenland and Antarctica and the scattered glaciers of certain mountains.

Each time the ice sheet thickened and expanded with the unmelted snows of winter after winter its growth meant a corresponding lowering of the ocean level. For directly or indirectly the moisture that falls on the earth's surface as rain or snow has been withdrawn from the reservoir of the sea. Ordinarily the withdrawal is a temporary one, the water being returned via the normal runoff of rain and melting snow. But in the glacial period the summers were cool, and the snows of any winter did not melt entirely but were carried over to the succeeding winter when the new snows found and covered them. So little by little the level of the sea dropped as the glaciers robbed it of its water and at the climax of each of the major glaciations the ocean all over the world stood at a very low level.

Today if you look in the right places, you will see the evidences of some of these old stands of the sea. Of course the strand marks left by the extreme low levels are now deeply covered by water and may be discovered only indirectly by

ing. But where, in past ages, the water level stood hi, it does today you can find its traces. In Samoa, at the foot a cliff wall now 15 feet above the present level of the sea, can find benches cut in the rocks by waves. You will find same thing on other Pacific islands, and on St. Helena in South Atlantic, on islands of the Indian Ocean, in the " Indies, and around the Cape of Good Hope.

Sea caves in cliffs now high above the battering assau the flung spray of the waves that cut them are eloquent of changed relation of sea and land. You will find such caves w ly scattered over the world. On the west coast of Norway is a remarkable, wave-cut tunnel. Out of the hard granite of island of Torghatten the pounding surf of a flooding intergla sea cut a passageway through the island, a distance of 530 feet, and in so doing removed nearly 5 million cubic of rock. The tunnel now stands 400 feet above the sea. I elevation is due in part to the elastic, upward rebound of crust after the melting of the ice.

During the other half f the cycle, when the seas lower and lower as the glaciers grew in thickness, the *sea were undergoing changes even more far-reaching (* dramatic. Every river felt the effect of the lowering sea, waters were speeded in their course to the ocean and gi new strength for the deepening and cutting of its channel. Following the downward-moving shorelines, the rivers extended their courses over the drying sands and muds of what only recently had been the sloping sea bottom. Here the rushing torrents—swollen with melting glacier water—picked up great quantities of loose mud and sand and rolled into the sea as a turgid flood.

During one or more of the Pleistocene lowerings of sea level, the floor of the North Sea was drained of its water and for a time became dry land. The rivers of northern Europe and of the B tish Isles followed the retreating waters seaward. Eventually the Rhine captured the whole drainage system of the Thames. The Elbe and the Weser became one river The Seine rolled through what is now the English Channel and cut itself a trough out across the continental shelf—perhaps the same drowned channel now discernible by soundings beyond Land's End.

The greatest of all Pleistocene glaciations came rather late in the period—probably only about 00 thousand years ago, and well within the time of man. The tremendous lowering of sea levels must have affected the life of Paleolithic man. Certainly he was able, at more than one period, to walk across a w bridge at Bering Strait, which became dry land when the level of the ocean dropped below this shallow shelf. There were

other land bridges, created in the same way. As the ocean receded from the coast of India, a long submarine bank became a shoal, then finally emerged, and primitive man walked across Adam's Bridge to the island of Ceylon.

Many of the settlements of ancient man must have been located on the seacoast or near the great deltas of the rivers, and relics of his civilization may lie in caves long since covered by the rising ocean. Our meager knowledge of Paleolithic man might be increased by searching along these old drowned shorelines. One archaeologist has recommended searching shallow portions of the Adriatic Sea, with 'submarine boats casting strong electric lights' or even with glass-bottomed boats and artificial light in the hope of discovering the outlines of shell heaps—the *kitchen middens* of the early men who once lived here. Professor R. A. Daly has pointed out

"The last Glacial stage was the Reindeer Age of French history. Men then lived in the famous caves overlooking the channels of the French rivers, and hunted the reindeer which throve on the cool plains of France south of the ice border. The Late-Glacial rise of general sealevel was necessarily accompanied by a rise of the river waters downstream. Hence the lowest caves are likely to have been partly or wholly drowned. There the search for more relics of Paleolithic man should be pursued.

Some of our Stone Age ancestors must have known the rigors of life near the glaciers. While men as well as plants and animals moved southward before the ice, some must have remained within sight and sound of the great frozen wall. To these the world was a place of storm and blizzard, with bitter winds roaring down out of the blue mountain of ice that dominated the horizon and reached upward into gray skies, all filled with the roaring tumult of the advancing glacier and with the thunder of moving tons of ice breaking away and plunging into the sea.

But those who lived half the earth way on some sunny coast of the India Ocean, walked and hunted on dry land over which the sea, only recently had rolled deeply. These men knew nothing of the distant glaciers, nor did they understand that they walked and hunted where they did because quantities of ocean water were frozen as ice and snow in a distant land.

In any imaginative reconstruction of the world of the Ice Age we are plagued by one tantalizing uncertainty how low did the ocean level fall during the period of greatest spread of the glaciers when unknown quantities of water were frozen in the ice? Was it only a moderate fall of 200 or 300 feet—a change paralleled many times in geologic history in the ebb and

From *The Changing World of the Ice Age*, 1934 edition, Yale University Press, p. 210.

flow of the epicontinental seas? Or was it a dramatic down of the ocean by 2000, even 3000 feet?

Each of these various levels has been suggested as an possibility by one or more geologists. Perhaps it is not surpr that there should be such radical disagreement. It has been about a century since Louis Agassiz gave the world its derstanding of the moving mountains of ice and their dom ing effect on the Pleistocene world. Since then, men in all p of the earth have been patiently accumulating the facts constructing the events of those four successive advances retreats of the ice. Only the present generation of led by such daring thinkers as Daly have understood that thickening of the ice sheets meant a corresponding lowering the ocean, and that with each retreat of the melting ice a turning flood of water raised the sea level.

Of this 'alternate robbery and restitution' most have taken a conservative view and said that the greatest low ing of the sea level could not have amounted to more than 4 feet, possibly only half as much. Most of those who a u the drawing down was much greater base their reasoning the submarine canyons, those deep gorges cut in the tinental slopes. The deeper canyons lie a mile or more below present level of the sea. Geologists who maintain that at l the upper parts of the canyons were stream-cut say that the se level must have fallen enough to permit this during the Pleistocene glaciation.

This question of the farthest retreat of the sea into its basins must await further searchings into the mysteries of the ocean. We seem on the verge of exciting new discoveries. Now oceanographers and geologists have better instruments than ever before to probe the depths of the sea, to sample its rocks and deeply layered sediments, and to read with greater clarity the dim pages of past history

Meanwhile, the sea ebbs and flows in these grander tides of earth, whose stages are measurable not in hours but in millennia—tides so vast they are invisible and uncomprehended by the senses of man. Their ultimate cause, should it ever be discovered, may be found to be deep within the fiery center of the earth, or it may lie somewhere in the dark spaces of the universe.

# Part II THE RESTLESS SEA

## 9 Wind and Water

*The wind's feet shine along the sea.*
SWINBURNE

As THE waves roll in toward Lands End on the westernmost tip of England they bring the feel of the distant places of the Atlantic. Moving shoreward above the steeply rising floor of the deep sea, from dark blue water into troubled green, they pass the edge of 'soundings' and roll up over the continental shelf in confused ripplings and turbulence. Over the shoaling bottom they sweep landward, breaking on the Seven Stones of the channel between the Scilly Isles and Lands End, coming in over the sunken ledges and the rocks that roll out their glistening backs at low water. As they approach the rocky tip of Lands End, they pass over a strange instrument lying on the sea bottom. By the fluctuating pressure of their rise and fall they tell this instrument many things of the distant Atlantic waters from which they have come, and their messages are translated by its mechanisms into symbols understandable to the human mind.

If you visited this place and talked to the meteorologist in charge, he could tell you the life histories of the waves that are rolling in, minute by minute and hour after hour, bringing their messages of far-off places. He could tell you where the waves were created by the action of wind on water, the strength of the winds that produced them, how fast the storm is moving, and how soon, if at all, it will become necessary to raise storm warnings along the coast of England. Most of the waves that roll over the recorder at Lands End, he would tell you, are born in the stormy North Atlantic eastward from Newfoundland and south of Greenland. Some can be traced to tropical storms on the [illegible] side of the Atlantic, moving through the West Indies and along the coast of Florida. A few have rolled up from the [illegible] part of the world, taking a great-circle [illegible] way from Cape Horn to Lands End, a journey of 6000 [illegible]

On the coast of California wave recorders have [illegible] swell from as great distance, for some of the surf [illegible] on that coast in summer is born in the [illegible] Southern Hemisphere. The Cornwall recorders

flow of the epicontinental seas? Or was it a dramatic down of the ocean by 2000, even 3000 feet?

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almost inaccessible part of its empire, which could have been sounded in the ordinary way only at great expense and with endless difficulty. Like much of our new knowledge of waves, this practical method was born of wartime necessity.

Forecasts of the state of the sea and particularly the height of the surf became regular preliminaries to invasion in the second World War, especially on the exposed beaches of Europe and Africa. But application of theory to practical conditions was at first difficult, so was the interpretation of the actual effect of any predicted height of surf or roughness of sea surface on the transfer of men and supplies between boats or from boats to beaches. This first attempt at practical military oceanography was, as one naval officer put it, a 'most frightening lesson' concerning the almost desperate lack of basic information on the fundamentals of the nature of the sea.

As long as there has been an earth, the moving masses of air that we call winds have swept back and forth across its surface. And as long as there has been an ocean, its waters have stirred to the passage of the winds. Most waves are the result of the action of wind on water. There are exceptions, such as the tidal waves sometimes produced by earthquakes under the sea. But the waves most of us know best are wind waves.

It is a confused pattern that the waves make in the open sea—a mixture of countless different wave trains, intermingling, overtaking, passing, or sometimes engulfing one another; each group differing from the others in the place and manner of its origin, in its speed, its direction of movement; some doomed never to reach any shore, others destined to roll across half an ocean before they dissolve in thunder on a distant beach.

Out of such seemingly hopeless confusion the patient study of many men over many years has brought a surprising amount of order. While there is still much to be learned about waves, and much to be done to apply what is known to man's advantage, there is a solid basis of fact on which to reconstruct the life history of a wave, predict its behavior under all the changing circumstances of its life, and foretell its effect on human affairs.

Before constructing an imaginary life history of a typical wave, we need to become familiar with some of its physical characteristics. A wave has height, from trough to crest. It has length, the distance from its crest to that of the following wave. The period of the wave refers to the time required for succeeding crests to pass a fixed point. None of these dimensions is static; all change, but bear definite relations to the wind, the depth of the water, and many other matters. Furthermore, the water that composes a wave does not advance with it across the sea; each water particle describes a circular or

bit with the passage of the wave form, but returns very to its original position. And it is fortunate that this is so, the huge masses of water that comprise a wave actually across the sea, navigation would be impossible. Those who professionally in the lore of waves make frequent use picturesque expression—the 'length of fetch. The 'fetch is distance that the waves have run, under the drive of a w blowing in a constant direction, without obstruction. greater the fetch, the higher the waves. Really large waves not be generated within the confined space of a bay or a sea. A fetch of perhaps 600 to 800 miles, with winds of velocity is required to get up the largest ocean waves.

Now let us suppose that, after a period of calm, a develops far out in the Atlantic, perhaps a thousand miles the New Jersey coast where we are spending summer hol Its winds blow irregularly with sudden gusts, shifting directi but in general blowing shoreward. The sheet of water u wind responds to the changing pressures. It is no longer a surface: it becomes furrowed with alternating troughs ridges. The waves move toward the coast, and the wind created them controls their destiny. As the storm and the waves move shoreward, they receive energy from wind and increase in height. Up to a point they will continue take to themselves the fierce energy of the wind, growing height as the strength of the gale is absorbed, but when a wa becomes about a seventh as high from trough to crest as distance to the next crest, it will begin to topple in whitecaps. Winds of hurricane force often blow the tops off the waves by their sheer violence: in such a storm the highest waves may develop after the wind has begun to subside.

But to return to our typical wave, born of wind and water far out in the Atlantic, grown to its full height on the energy of the winds, with its fellow waves forming a confused, irregular pattern known as a 'sea.' As the waves gradually pass out of the storm area their height diminishes, the distance between successive crests increases, and the 'sea' becomes a 'swell,' moving at an average speed of about 15 miles an hour. Near the coast a pattern of long, regular swells is substituted for the turbulence of open ocean. But as the swell enters shallow water a startling transformation takes place. For the first time in its existence the wave feels the drag of shoaling bottom. Its speed slackens, crests of following waves crowd in toward it, abruptly its height increases and the wave form steepens. Then with a spilling, tumbling rush of water falling down into its trough, it dissolves in a seething confusion of foam.

An observer sitting on a beach can make at least an urgent guess whether the surf spilling out onto the san

sea has been produced by a gale close offshore or by a distant storm. Young waves, only recently shaped by the wind, have a steep, peaked shape even well out at sea. From far out on the horizon you can see them forming whitecaps as they come in; bits of foam are spilling down their fronts and boiling and bubbling over the advancing face, and the final breaking of the wave is a prolonged and deliberate process. But if a wave, on coming into the surf zone, rears high as though gathering all its strength for the final act of its life, if the crest forms all along its advancing front and then begins to curl forward, if the whole mass of water plunges suddenly with a booming roar into its trough—then you may take it that these waves are visitors from some very distant part of the ocean, that they have traveled long and far before their final dissolution at your feet.

What is true of the Atlantic wave we have followed is true, in general, of wind waves the world over. The incidents in the life of a wave are many. How long it will live, how f r it will travel, to what manner of end it will come are all determined, in large measure, by the conditions it meets in its progression across the face of the sea. For the one essential quality of a wave is that it moves; anything that retards or stops its motion dooms it to dissolution and death.

Forces within the sea itself m y affect a wave most profoundly. Some of the most terrible furies of the ocean are unleashed when tidal currents cross the path of the waves or move in direct opposition to them. This is the cause of the famous 'roosts' of Scotland, like the one off Sumburgh Head, at the southernmost tip of the Shetland Islands. During northeasterly winds the roost is quiescent, but when the wind-born waves roll in from any other quarter they encounter the tidal currents, either streaming shoreward in flood or seaward on the ebb. It is like the meeting of two wild beasts. The battle of the wa es and tides is fought over an area of sea that may be three miles wide when the tides are running at full strength, first off Sumburgh Head, then gradually shifting seaward subsiding only with the temporary slackening of the tide. 'In this confused, tumbling, and bursting sea, vessels often become entirely unmanageable and sometimes founder,' says the *British Islands Pilot*, 'while others have been tossed bout for days together.' Such da gerous waters have been personified in many parts of the world by names that are handed down through generations of seafaring men. As in the time of our grandfathers and of their grandfathers, the Bore of Duncansby nd the Merry Men of Mey rage at opposite ends of the Pentland Firth. The sailing direction for the Firth in the *North Sea Pilot* for 1875 contained a warning to mariners, which is repeated the modern *Pilot*.

Before entering the Pentland Firth all vessels should make [illegible] [illegible] the passage of small vessels be attempted even in fine weather, as the [illegible] which are [illegible] in the entrance, [illegible] the [illegible] in a moment [illegible] for making arrangements."

Such roosts are caused by the meeting of swells from ocean and opposing tidal currents, so that at the east of the Firth the Roost of Duncansby is to be feared with swells and a flood tide, and at the west end the Merry Men make their trouble with the ebb tide and a westerly. Then, according to the Pilot, [illegible] sea is raised which [illegible] imagined by those who have never experienced it.

Such a rip [illegible] often [illegible] to the near-by coast very fury and [illegible] of the struggle waves and tide. Thomas Stevenson long ago observed long as the Sumburgh roost was breaking and crating off the Head there was little surf on shore, once the streng the tide was spent and it could no longer run down the heavy surf rolled in against the coast and rose to great the cliffs. And in the western Atlantic, the confused running tidal currents at the mouth of the Bay of Fu such strong opposition to waves approaching from arter from southwest to southeast that such surf as deve within the Bay is almost entirely local in its origin.

Out in the open sea, a train of waves encountering a host wind may be rapidly destroyed, for the power that created wave may also destroy it. So a fresh trade wind in the Atlan has often flattened out the swells as they rolled down land toward Africa. Or a friendly wind, suddenly s to blow in the direction the waves are moving, may height to increase at the rate of a foot or two per m a group of moving ridges has been created, the wind to fall into the troughs between them to push up th rapidly.

Rocky ledges, shoals of sand or cl islands in the mouths of bays all pla the waves that advance toward shore from the open ocean toward the shore land seldom reach it in full strength. passing over that great submerged high Bank, the crests of whose highest b over the Cultivator Shoals. The hindrance bars and of the tidal currents that sw turn, robs the long ocean swells of the scattered within a bay or about its mouth

strength of the waves that the head of the bay is free from surf. Even scattered reefs off a coast may offer it great protection, by causing the highest waves to break there, so that they never reach the shore.

Ice, snow, rain—all are enemies of the waves and under proper conditions may knock down a sea or cushion the force of surf on a beach. Within loose pack ice a vessel may count on smooth seas even if a gale is raging and surf is breaking heavily about the edges of the pack. Ice crystals forming in the sea will smooth the waves by increasing the friction between water particles; even the delicate, crystalline form of a snow flake has such an effect on a smaller scale. A hail storm will knock down a rough sea, and even a sudden downpour of rain may often turn the surface of the ocean to oiled-silk smoothness, rippling to the passage of the swells.

The divers of ancient times who carried oil in their mouths to release beneath the surface when rough water made their work difficult were applying what every seaman today knows—that oil appears to have a calming effect on the free waves of the open ocean. Instructions for the use of oil in emergencies at sea are carried by most official sailing directions of maritime nations. Oil has little effect on surf, however, once the dissolution of the wave form has begun.

In the Southern Ocean where the waves are not destroyed by breaking on any beach, the great swells produced by the westerly winds roll around and around the world. Here the longest waves and those with the greatest sidewise expanse of crest are formed. Here, it might be supposed, the highest waves would also be found. Yet there is no evidence that the waves of the Southern Ocean surpass the gia ts of any other ocean. A long series of reports culled from the publications of engineers and ships' officers show that waves higher than 25 feet from trough to crest are rare in all oceans. Storm w ves may grow twice as high, and if a full gale blows long enough in one direction to have a fetch of 600 to 800 miles, the resulting waves may be even higher. The greatest possible height of storm waves at sea is a much debated question, with most textbooks citing a conservative 60 feet, and mariners stubbornly describing much higher waves. Throughout the century that has followed the report of Dumont d'Urville that he encountered waves 100 feet high off the Cape of Good Hope, science generally has viewed such figures with skepticism. Yet there is one record of a giant w ve which, because of the method of measurement, seems to be accepted as reliable.

*In February 1933 the U.S.S. Ramapo while proceeding from Manila to San Diego, encountered seven days of*

weather The storm was part of a weather disturbance extended all the way from Kamchatka to New York and mitted the winds an unbroken fetch of thousands of m During the height of the storm the *Ramapo* maintained a cou running down the wind and with the sea. On 6 February the gale reached its fiercest intensity Winds of 68 knots came gusts and squalls, and the seas reached mountainous he While standing watch on the bridge during the early of that day one of the officers of the *Ramapo* saw in u light, a great sea rising astern to a level above an iron strap the crow's nest of the mainmast. The *Ramapo* was on keel and her stern was in the trough of the sea. These stances made possible an exact line of sight from the bridge the crest of the wave, and simple mathematical calculati based on the dimensions of the ship gave the height of wave. It was 112 feet.

Waves have taken their toll of shipping and of human l open sea, but it is around the shorelines of the world ey are most destructive. Whatever the height of storm sea, there is abundant evidence, as some of the case that follow will show that breaking surf and the upward water masses from thundering breakers may engulf shatter buildings, and hurl stones through lighthouse wi anywhere from 100 to 300 feet above the sea. Before the of such surf piers and breakwaters and other shore insta are fragile as a child's toys.

Almost every coast of the world is visited periodically by lent storm surf but there are some that have never kn sea in its milder moods. 'There is not in the world a terrible than this!' exclaimed Lord Bryce of Tierra del F where the breakers roar in upon the coast with a voice according to report, can be heard 20 miles inland on a night. 'The sight of such a coast,' Darwin had written diary 'is enough to make a landsman dream for a week death, peril, and shipwreck.

Others claim that the Pacific coast of the United States northern California to the Straits of Juan de Fuca has a heavy as any in the world. But it seems unlikely that any is visited more wrathfully by the sea's waves than the Shetl and the Orkneys, in the path of the cyclonic storms that eastward between Iceland and the British Isles. All the and the fury of such a storm, couched almost in prose, are contained in the usually prosaic B itish Island.

'In the terrific gales which usually occur four or five every year all distinction between air and water is lost, est objects are obscured by spray and everything veloped in a thick smoke' upon the open coast the sea

ocre, and striking upon the rocky shores rises in foam for several hundred feet and spreads over the whole country

The sea, however is not so heavy in the violent gales of short continuance as when an ordinary gale has been blowing for many days, the whole force of the Atlantic is then beating against the shores of the Orkneys, rocks of many tons in weight are lifted from their beds, and the roar of the surge may be heard for twenty miles; the breakers rise to the height of 60 feet, and the broken sea on the North Shoal, which lies 12 miles northwestward of Costa Head, is visible at Skall and Birsay

The first man who ever measured the force of an ocean wave was Thomas Stevenson, father of Robert Louis Stevenson developed the instrument known as a wave dynamometer and with it studied the waves that battered the coast of his native Scotland. He found that in winter gales the force of a wave might be as great as 6,000 pounds to the square foot. Perhaps it was waves of this strength that destroyed the breakwater at Wick on the coast of Scotland in December storm in 1872. The seaward end of the Wick breakwater consisted of a block of concrete weighing more than 800 tons, bound solidly with iron rods to underlying blocks of stone. During the height of this winter gale the resident engineer watched the onslaught of the waves from a point on the cliff above the breakwater Before his incredulous eyes, the block of concrete was lifted up and swept shoreward. After the storm had subsided divers investigated the wreckage. They found that not only the concrete monolith but the stones it was attached to had been carried away The waves had torn loose lifted, and bodily moved a mass weighing not less than 1,350 tons or 2,700,000 pounds. Five years later it became clear that this feat had been mere dress rehearsal, for the new pier weighing about 2,600 tons, was then carried away in another storm.

A list of the perverse nd freakish doings of the sea can easily be compiled from the records of the keepers of lights on lonely ledges at sea, or on rocky headlands exposed to the full strength of storm surf At Unst the most northern of the Shetland I lands, a door in the lighthouse was broken open 195 feet above the sea. At the Bishop Rock Light, on the English Channel, a bell was torn away from its place of attachment 100 feet above high water during a winter gale. About the Bell Rock Light on the coast of Scotland one November day a heavy ground swell was running, although there was no w nd Suddenly one of the swells rose bout the tower mounted to the gilded ball top the lantern, 117 feet above the rock, away ladder that was attached to the tower 86 feet water There have been happenings that, to

tinged with the supernatural, like that at the Eddystone Light 1840. The entrance door of the tower had been made fast by strong bolts, as usual. During a night of heavy seas the was broken open *from within*, and all its iron bolts and h were torn loose. Engineers say that such a thing happens as result of pneumatic action—the sudden back draught by the recession of a heavy wave combined with an release of pressure on the outside of the door

On the Atlantic coast of the United States, the 97-foot t on Minot's Ledge in Massachusetts is often completely veloped by masses of water from breaking surf and an earli light on this ledge was swept away in 1851 Then there is often quoted story of the December storm at Trinidad Light on the coast of northern California. As the keep watched the storm from his lantern 196 feet above high he could see the near-by Pilot Rock engulfed again and aga by waves that swept over its hundred-foot crest. Then a wave larger than the rest, struck the cliff at the base of the light. seemed to rise in a solid wall of water to the level of the lantern and it hurled its spray completely over the tower The shock the blow stopped the revolving of the light.

Along a rocky coast, the waves of a severe storm are likely be armed with stones and rock fragments, which greatly in crease their destructive power Once a rock weighing 1. pounds was hurled high above the lightkeeper's house on Tillamook Rock on the coast of Oregon, 100 feet above sea level. In falling, it tore a 20-foot hole through the roof The same day showers of smaller rocks broke many panes of glass in the lantern, 132 feet above the sea. The most amazing of such stories concerns the lighthouse at Dunnet Head, which stands on the summit of a 300-foot cliff at the southwestern entrance to Pentland Firth. The windows of this light have been broken repeatedly by stones swept from the cliff and tossed aloft by waves.

For millennia beyond computation, the sea's waves have battered the coastlines of the world with erosive effect, here cutting back a cliff there stripping away tons of sand from a beach, and yet again in a reversal of their destructiveness, building up a bar or a small island. Unlike the slow geologic changes that bring about the flooding of half a continent, the work of the waves is attuned to the brief span of human life, and so the sculpturing of the continent's edge is something each of us can see for ourselves.

The high clay cliff of Cape Cod, rising at Eastham and running north until it is lost in the sand dunes near Peaked Hill, is wearing back so fast that half of the ten acres which the Government acquired as a site for the Highland Light has disappeared,

and the cliffs are said to be receding about three feet a year. Cape Cod is not old, in geologic terms, being the product of the glaciers of the most recent ice age, but apparently the waves have cut away since its formation, a strip of land some two miles wide. At the present rate of erosion, the disappearance of the outer cape is foredoomed. It will presumably occur in another 4000 or 5000 years.

The sea's method on a rocky coast is to wear it down by grinding, to chisel out and wrench away fragments of rock, each of which becomes a tool to wear away the cliff. And as masses of rock are undercut, a whole huge mass will fall into the sea, there to be ground in the mill of the surf and to contribute more weapons for the attack. On a rocky shore this grinding and polishing of rocks and fragments of rocks goes on incessantly and audibly, for the breakers on such a coast have a different sound from those that have only sand to work with—a deep-toned mutter and rumble not easily forgotten, even by one who strolls casually along such a beach. Few people have heard the sounds of the surf mill practically from within the sea, as described by Henwood after his visit to a British mine extending out under the ocean:

"When standing beneath the base of the cliff, and in that part of the mine where but nine feet of rock stood between us and the ocean, the heavy roll of the larger boulders, the ceaseless grinding of the pebbles, the fierce thundering of the billows, with the crackling and boiling as they rebounded, placed a tempest in its most appalling form too vividly before me ever to be forgotten. More than once doubting the protection of our rocky shield we retreated in affright; and it was only after repeated trials that we had confidence to pursue our investigations."*

Great Britain, an island, has always been conscious of that powerful marine gnawing by which her coasts are eaten away. An old map dated 1786 and prepared by the county surveyor John Tuke, gives a long list of lost towns and villages on the Holderness Coast. Among them are notations of Hornsea Burton, Hornsea Beck, and Hartburn—"washed away by the sea"; of Ancient Withernsea, Hyde, or Hythe—"lost by the sea." Many other old records allow comparison of present shorelines with former ones and show astonishing annual rates of cliff erosion on many parts of the coast—up to 15 feet at Holderness, 19 feet between Cromer and Mundesley, and 15 to 45 feet at Southwold. "The configuration of the coastline of Great Britain, one of her present engineers writes, "is not the same for two consecutive days."

And yet we owe some of the most beautiful and interesting shoreline scenery to the sculpturing effect of moving

* From Transactions, Geol. Soc. Corn. . . ., vol. . . ., 1843.

shocks, the sea receded from the shore, leaving ships that had been anchored in 40 feet of water stranded in mud then the water returned in a great wave, and boats were carried a quarter of a mile inland.

This ominous withdrawal of the sea from its normal stand is often the first warning of the approach of seismic sea waves. Natives on the beaches of Hawaii on the first of April 1946 were alarmed when the accustomed voice of the breakers was suddenly stilled, leaving a strange quiet. They could not know that this recession of the waves from the reefs and the shallow coastal waters was the sea's response to an earthquake on the steep slopes of a deep trench off the island of Unimak in the Aleutian chain, more than 2000 miles away or that in a matter of moments the water would rise rapidly as though the tide were coming in much too fast, but without surf. The rise carried the ocean waters 25 feet or more above the normal levels of the tide. According to an eyewitness account.

The waves of the tsunami swept toward shore with steep fronts and great turbulence Between crests the water withdrew from shore, exposing reefs, coastal mud-flats, and harbor bottoms for distances up to 500 feet or more from the normal strand-line. The outflow of the water was rapid and turbulent, making a loud hissing, roaring, and rattling noise. At several places houses were carried out to sea, and in some areas even large rocks and blocks of concrete were carried out onto the reefs People and their belongings were swept to sea, some being rescued hours later by boats and life rafts dropped from planes.

In the open ocean the w ves produced by the Aleutian quake were only bout foot or two high and would not be noticed from vessels. Their length, however was enormous, with a distance of bout 90 miles between succeeding crests. It took the waves less than 5 hours to reach the Hawaiian chain, 2300 miles distant, so they must have moved at an average speed of about 470 miles per hour Along eastern Pacific shores, they were recorded as far as the Southern Hemisphere as Valparaiso, Chile the distance of 8066 miles from the epicenter being covered by the waves in about 18 hours.

This particular occurrence of seismic sea waves had one result that distinguished it from all its predecessors. It set people to thinking that perhaps we now know enough about such waves and how they behave that w rning system could be devised which would rob them of the terror of the unexpected. Seismologists and specialist on w ves and tides co-operated, and now such ystem has been established to protect the Hawaiian Islands. A network of stations equipped with

From Annual Rept. Smithsonian Inst., 1947

so regular and so low that often they are unnoticed as they pass through the short, choppy, new-formed waves of other seas. But when a swell approaches a coast and feels beneath it the gradually shoaling bottom, it begins to 'peak up' into a high, steep wave; within the surf zone the steepening becomes abruptly accentuated, a crest forms, breaks, and a great mass of water plunges downward.

Winter swell on the west coast of North America is the product of storms that travel south of the Aleutians into the Gulf of Alaska. Swell reaching this same coast during the summer has been traced back to its origin in the Southern Hemisphere belt of the 'roaring forties,' several thousand miles south of the equator. Because of the direction of the prevailing winds, the American east coast and the Gulf of Mexico do not receive the swell from far distant storms.

The coast of Morocco has always been particularly at the mercy of swell, for there is no protected harbor from the Strait of Gibraltar southward for some 500 miles. The rollers that visit the Atlantic islands of Ascension, St. Helena, South Trinidad, and Fernando de Noronha are historic. Apparently the same sort of waves occur on the South American coast near *Rio de Janeiro, where they are known as resacas;* others of kindred nature, having run their course from storms in the west wind belt of the South Pacific, attack the shores of the Paumotos Islands; still others have been responsible for the well-known 'surf days' that plague the Pacific coast of South America. According to Robert Cushman Murphy, it was formerly the custom of shipmasters in the guano trade to demand a special allowance for a certain number of days during which the loading of their vessels would be interrupted by the swell. On such surf days 'mighty rollers come pouring over the sea wall, and have been known to carry away forty-ton freight cars, to uproot concrete piers, and to twist iron rails like wire.'

The slow progression of swell from its place of origin made it possible for the Moroccan Protectorate to establish a service for the prediction of the state of the sea. This was done in 1921, after long and troublesome experience with wrecked vessels and wharves. Daily telegraphic reports of the condition of the sea give advance notice of troublesome surf days. Warned of the approach of swells, ships in port may seek safety in the open sea. Before this service was established, the port of Casablanca had once been paralyzed for seven months, and St. Helena had seen the wreckage of practically all the ships in her harbor on one or more occasions. Modern wave-recording instruments like those now being tested in England and the United States will soon provide even greater security for all such threats.

It is always the unseen that most deeply stirs our imagination,

are so regular and so low that often they are unnoticed as they pass through the short, choppy new-formed waves of other areas. But when a swell approaches a coast and feels beneath it the *gradually* shoaling bottom, it begins to 'peak up' into a high, steep wave; within the surf zone the steepening becomes abruptly accentuated, a *crest forms*, breaks, and a great mass of water plunges downward.

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# 10 Wind, Sun and the Spinning of the Earth

*For thousands upon thousands of years the sunlight and the sea and the masterless winds have held tryst together.*
LLEWELYN POWYS

As the *Albatross III* groped through fog over Georges Bank all of one week in the midsummer of 1949 those of us aboard had a personal demonstration of the power of a great ocean current. There was never less than a hundred miles of cold Atlantic water between us and the Gulf Stream, but the winds blew persistently from the south and the warm breath of the Stream rolled over the Bank. The combination of warm air and cold water spelled unending fog. Day after day the *Albatross* moved in a small circular room, whose walls were soft gray curtains and whose floor had a glassy smoothness. Sometimes a petrel flew with swallow-like flutterings, across this room, entering and leaving it by passing through its walls as if by sorcery. Evenings, the sun, before it set, was a pale silver disc hung in the ship's rigging, the drifting streamers of fog picking up a diffused radiance and creating a scene that set us to searching our memories for quotations from Coleridge. The sense of a powerful presence felt but not seen, its nearness made manifest but never revealed, was infinitely more dramatic than a direct encounter with the current.

The permanent currents of the ocean are, in a way, the most majestic of her phenomena. Reflecting upon them, our minds are at once taken out from the earth so that we can regard, as from another planet, the spinning of the globe, the winds that deeply trouble its surface or gently encompass it, and the influence of the sun and the moon. For all these cosmic forces are closely linked with the great currents of the ocean, earning for them the adjective I like best of all those applied to them—the planetary currents.

Since the world began, the ocean currents have undoubtedly changed their courses many times (we know, for example, that the Gulf Stream is no more than about 60 million years old); but it would be a bold writer who would try to describe their pattern in the Cambrian Period, for example, or in the Devonian, or in the Jurassic. So far as the brief period of human history is concerned, however, it is most unlikely that there has been any important change in the major patterns of oceanic circulation, and the first thing that impresses us about the currents is their permanence. This is not surprising, for the

been longest known to seafaring men and best studied by oceanographers. The strongly running Equatorial Currents were familiar to generations of seamen in the days of sail. So determined was their set to westward that vessels intending to pass down into the South Atlantic could make no headway unless they had gained the necessary easting in the region of the southeast trades. Ponce de Leon's three ships, sailing south from Cape Canaveral to Tortugas in 1513 sometimes were unable to stem the Gulf Stream, and 'although they had great wind, they could not proceed forward, but backward. A few years later Spanish shipmasters learned to take advantage of the currents, sailing westward in the Equatorial Current, but returning home via the Gulf Stream as far as Cape Hatteras, whence they launched out into the open Atlantic.

The first chart of the Gulf Stream was prepared about 1769 under the direction of Benjamin Franklin while he was Deputy Postmaster General of the Colonies. The Board of Customs in Boston had complained that the mail packets coming from England took two weeks longer to make the westward crossing than did the Rhode Island merchant ships. Franklin, perplexed took the problem to a Nantucket sea captain, Timothy Folger who told him this might very well be true because the Rhode Island captains were well acquainted with the Gulf Stream and avoided it on the westward crossing, whereas the English captains were not. Folger and other Nantucket whalers were personally familiar with the stream because, he explained,

'In our pursuit of whales, which keep to the sides of it but are not met within it, we run along the side and frequently cross it to change our side and in crossing it have sometimes met and spoke with those packets who were in the middle of it and stemming it. We have informed them that they were stemming a current that was against them to the value of three miles an hour and advised them to cross it, but they were too wise to be counselled by simple American fishermen

Franklin, thinking 'it was a pity no notice was taken of this current upon the charts, asked Folger to mark it out for him. The course of the Gulf Stream was then engraved on an old chart of the Atlantic and sent by Franklin to Falmouth, England, for the captains of the packets, 'who slighted it, however It was later printed in France and after the Revolution was published in the *Transactions of the American Philosophical Society* The thriftiness of the Philosophical Society editors led them to combine in one plate Franklin's chart and a wholly separate figure intended to illustrate a paper by John Gilpin on the Annual Migrations of the Herring. Some later historians have erroneously assumed a connection between Franklin's

From Am. Phil. Soc. Trans., vol. 2, 786.

conception of the Gulf Stream and the insert in the upper corner (see back end paper).

Were it not for the deflecting barrier of the Panamanian Is mus, the North Equatorial Current would cross into the Paci as indeed it must have done through the many geologic when the continents of North and South America were rated. After the Panama ridge was formed in the late C ceous period, the current was doubled back to the northeast re-enter the Atlantic as the Gulf Stream. From the Channel eastward through the Florida Straits the Stream impressive proportions. If thought of in the time-honored ception of a 'river' in the sea, its width from bank to bank is ! miles. It is a mile deep from surface to river bed. It flows wi a velocity of nearly 3 knots and its volume is that of hundred Mississippis.

Even in these days of Diesel power the coastwise off southern Florida shows a wholesome respect for the Gul Stream. Almost any day if you are out in a small boat bel Miami, you may see the big freighters and tankers south in a course that seems surprisingly close to the K Landward is the almost unbroken wall of submerged where the big niggerhead corals send their solid bulks up within a fathom or two of the surface. To seaward is the G Stream, and while the big boats could fight their way sou against it, they would consume much time and fuel in doing so Therefore they pick their way with care between the reefs the Stream.

The energy of the Stream off southern Florida probably results from the fact that here it is actually flowing downhill. Strong easterly winds pile up so much surface water in the narrow Yucatan Channel and in the Gulf of Mexico that the sea level there is higher than in the open Atlantic. At Cedar Keys, on the Gulf coast of Florida, the level of the sea is 19 centimeters (about 7½ inches) higher than at St. Augustine. There is further unevenness of level within the current itself. The lighter water is deflected by the earth's rotation toward the right side of the current, so that within the Gulf Stream the sea surface actually slopes upward toward the right. Along the coast of Cuba, the ocean is about 18 inches higher than along the mainland, thus upsetting completely our notions that 'sea level' is a literal expression.

Northward, the Stream follows the contours of the continental slope to the offing of Cape Hatteras, whence it turns more to seaward, deserting the sunken edge of the land. But it has left its impress on the continent. The four beautifully sculptured capes of the southern Atlantic coast—Canaveral, Fear, Lookout, Hatteras—apparently have been molded by powerful

eddies set up by the passage of the Stream. Each is a cusp projecting seaward, between each pair of capes the beach runs in a long curving arc—the expression of the rhythmically swirling waters of the Gulf Stream eddies.

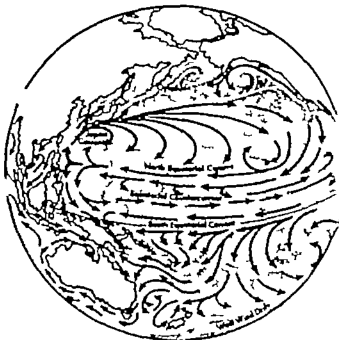
Beyond Hatteras, the Stream leaves the shelf, turning northeastward, as a narrow meandering current, always sharply separated from the water on either side. Off the 'tail' of the Grand Banks the line is most sharply drawn between the cold, bottle-green arctic water of the Labrador Current and the warm indigo blue of the Stream. In winter the temperature change across the current boundary is so abrupt that as a ship crosses into the Gulf Stream her bow may be momentarily in water 20° warmer than that at her stern, as though the 'cold wall' were a solid barrier separating the two water masses. One of the densest fog banks in the world lies in this region over the cold water of the Labrador Current—a thick, blanketing whiteness that is the atmospheric response to the Gulf Stream's invasion of the cold northern seas.

Where the Stream feels the rise of the ocean floor known as the 'tail' of the Grand Banks, it bends eastward and begins to spread out into many complexly curving tongues. Probably the force of the arctic water the water that has come down from Baffin Bay and Greenland, freighting its icebergs, helps push the Stream to the east—that, and the deflecting force of the earth's rotation, always turning the currents to the right. The Labrador Current itself (being a southward-moving current) is turned in toward the mainland. The next time you wonder why the water is so cold at certain coastal resorts of the eastern United States, remember that the water of the Labrador Current is between you and the Gulf Stream.

Passing across the Atlantic the Stream becomes less a current than a drift of water fanning out in three main directions: southward into the Sargasso northward into the Norwegian Sea, where it forms eddies and deep vortices eastward to warm the coast of Europe (some of it even to pass into the Mediterranean) and thence as the Canary Current to rejoin the Equatorial Current and close the circuit.

The Atlantic currents of the Southern Hemisphere are practically a mirror image of those of the Northern. The great spiral moves counterclockwise—west, south, east, north. Here the dominant current is in the eastern instead of the western part of the ocean. It is the Benguela Current, a river of cold water moving northward along the west coast of Africa. The South Equatorial C rrent, in mid-ocean a powerful stream (the *Challenger* scientists said it poured past St Paul Rocks like mill-race) loses a subst ntial part of its waters to the North f off the coast of South America—about 6 million

second. The remainder becomes the Brazil Current, which cles south and then turns east as the South Atlantic or Antarc Current. The whole is a system of shallow water mo involving throughout much of its course not more than upper hundred fathoms.



The North Equatorial Current of the Pacific is the longest westerly running current on earth, with nothing to deflect it in its 9000-mile course from Panama to the Philippines. There, meeting the barrier of the islands, most of it swings northward as the Japan Current—Asia's counterpart of the Gulf Stream. A small part persists on its westward course, feeling its way amid the labyrinth of Asiatic islands, part turns upon itself and streams back along the equator as the Equatorial Countercurrent. The Japan Current—called Kuroshio or Black Current because of the deep, indigo blue of its waters—rolls northward along the continental shelf off eastern Asia, until it is driven away from the continent by a mass of icy water—the Oyashio—that pours out of the Sea of Okhotsk and Bering Sea. The

Japan Current and Oyashio meet in a region of fog and tempestuous winds, as, in the North Atlantic, the meeting of the Gulf Stream and the Labrador Current is marked with fog. Drifting toward America, the Japan Current forms the northern wall of the great North Pacific eddy Its warm waters become



*Course of the great, wind-driven current systems of the Atlantic and Pacific oceans. Cold curr it p pear in white: warm or intermediate ones in black*

chilled with infusions of cold polar water from O shio the Aleutians, and Alaska. When it reaches the mainland Amer ica it is cool current, moving southward along he coast of California. There it is further cooled by updrafts f deep water and has much to do with the temperate summer climate of the American west coast. Off Lower California it rejoins the North Equatorial C rrent.

What with all the immensity of space in the South Pacific, we should expect t find here the most powerf ... all ocean urrents, but this does not seem to be

Equatorial Current has its course so frequently interrupted by islands, which are forever deflecting streams of its water into the central basin, that by the time it approaches Asia it is, during most seasons, a comparatively feeble current, lost in a confused and ill-defined pattern around the East Indies and Australia. The West Wind Drift or Antarctic Current—the poleward arc of the spiral—is born of the strongest winds in the world, roaring across stretches of ocean almost unbroken by land. The details of this, as of most of the currents of the South Pacific, are but imperfectly known. Only one has been thoroughly studied—the Humboldt—and this has so direct an effect on human affairs that it overshadows all others.

The Humboldt Current, sometimes called the Peru, flows northward along the west coast of South America, carrying waters almost as cold as the Antarctic from which it comes. But its chill is actually that of the deep ocean, for the current is reinforced by almost continuous upwelling from lower oceanic layers. It is because of the Humboldt that penguins live almost under the equator on the Galapagos Islands. In these cold waters, rich in minerals, there is an abundance of sea life perhaps unparalleled anywhere else in the world. The direct harvesters of this sea life are not men, but millions of sea birds. From the sun-baked accumulations of guano that whiten the coastal cliffs and islands, the South Americans obtain, at second hand, the wealth of the Humboldt Current.

Robert E. Coker who studied the Peruvian guano industry at the request of that government, gives a vivid picture of the life of the Humboldt. He writes of

> immense schools of small fishes, the anchobetas, which are followed by numbers of bonitos and other fishes and by sea lions, while at the same time they are preyed upon by the flocks of cormorants, pelicans, gannets, and other abundant sea birds. The long files of pelicans, the low-moving black clouds of cormorants, or the rainstorms of plunging gannets probably cannot be equaled in any other part of the world. The birds feed chiefly almost exclusively upon the anchobetas. The anchobeta, then, is not only the food of the larger fishes, but, as the food of the birds, it is the source from which is derived each year probably a score of thousands of tons of high-grade bird guano.

Dr Coker estimated the annual consumption of fish by the guano-producing birds of Peru as equal to a fourth of the total production of all United States fisheries. Because of this diet, which links the birds with all the minerals of the sea, their excrement is the most valuable and efficient fertilizer in the world.

Leaving the coast of South America at about the latitude of

From Bulletin, U. S. Bureau of Fisheries, vol. [illegible] viii, part 1, [illegible]

Cape Blanco, the Humboldt Current turns westward into the Pacific, carrying its cool waters almost to the equator About the Galapagos Islands it gives rise to a strange mixture of waters —the cool green of the Humboldt and the blue equatorial waters meeting in rips and foam lines, suggesting hidden movements and conflicts deep in the sea.

The conflict between opposing water masses may in places, be one of the most dramatic of the ocean's phenomena. Super ficial hissings and sighings, the striping of the surface waters with lines of froth, a confused turbulence and boiling, and even sounds like distant breakers accompany the displacement of the surface layers by deep water As visible evidence of the upward movement of the water masses, some of the creatures that inhabit the deeper places of the sea may be carried up bodily into the surface, there to set off orgies of devouring and being devoured such as Robert Cushman Murphy witnessed one night off the coast of Colombia from the schooner *Askoy* The night had been still and dark, but the behavior of the surface made it clear that deep water was rising and that some sort of conflict was in progress among opposing water masses far below the ship. All about the schooner small, steep waves leaped into being and dissolved in foaming whitecaps, pricked with the blue fire of luminescent organisms. Suddenly

'On either side, and at a bafflingly uncertain distance from the ship, dark line, like wall of advancing water seemed to be closing in upon us W could hear the splash and murmur of a troubled surface close by Presently we could see gleam of foam sprinkled with points of luminescence on the slowly proaching swell or head to the left. V gue and unfounded thoughts f marine earthquak bores occurred to Fallon and me together and we felt peculiarly helpless with a dismantled engine and no breeze to make the craft answer her helm. The dreamlike slowness of all that was going on, moreover gave me feeling that I had not yet fully shaken off the bonds of three hours slumber

'However when the dark, white-outlined menace reached us, it proved to be nothing more than field of the dancing water tossing its litil peaks mere foot or so into the air and beating tattoo on the steel flanks of Askoy

'Presently sharp hissing sound, different in character from the bursting of small wa es, came out f the darknes to tar board, and this was followed by strange sighings and puffings The puffers were blackfish, many scores, or perhaps hundreds f them, rolling and lumbering along and diving to pass beneath Askoy shortly before they reached her bilge We could hear the bacchanalian clamor of their rumblings nd belchings. In the long beam of the searchlight, the

proved to come from the jumping of small fishes. In all d[illegible]tions as far as the light carried, they were shooting into the [illegible] and pouring down like hail

The surface was seething, boiling with life, much of wh[illegible] was *de profundis*. Larvae of clawless lobsters, tinted jellyfis[illegible] nurse chains of salps, small herringlike fishes, a silvery hate[illegible] fish with its face bitten off, rudder fishes, hanging head dow[illegible]ward, luminous lantern-fishes with shining light pores, and purple swimming crabs, other creatures which we [illegible] not name at sight and much that was too small even to [illegible] distinctly

A general holocaust was in progress. The little fishes we[illegible] eating invertebrates or straining out the plankton the squi[illegible] were pursuing and capturing fish of various sizes and the blac[illegible] fish were no doubt enjoying the squids

As the night wore on, the amazing manifestations of abu[illegible]dance and devouring gradually almost imperceptibly d[illegible] away Eventually Askoy lay once more in water that seem[illegible] as still and dead as oil, and the lap-lap of skipping waves dr[illegible] off farther and farther into the distance until it was lost.

Although such exciting displays of upwelling are seen a[illegible] recognized by comparat vely few people the process takes pl[illegible] regularly off a number of coasts and at many places in the op[illegible] ocean. Wherever it occurs, it is responsible for a profusion [illegible] life. Some of the world's largest fisheries are dependent on u[illegible]welling. The coast of Algeria is famous for its sardine fisheri[illegible] the sardines are abundant here because upward streams [illegible] deep, cold water provide the minerals to support astronomic[illegible] numbers of diatoms The west coast of Morocco, the area o[illegible]posite the Canary and Cape Verde islands, and the southwe[illegible] coast of Africa are other sites of extensive upwelling and [illegible]sequent richness of marine lif There is an amazingly abu[illegible]dant fish fauna in the Arabian Sea near Oman and on t[illegible] Somali Coast near C pe H fun, both occurring in areas of co[illegible] water rising from the depths. In the South Equatorial Curre[illegible] north of Ascension Island is 'tongue of cold' produced by th[illegible] rise of sea water from the bottom. It is extraordinarily rich i[illegible] plankton. Upwelling around the island of South Georgia, ea[illegible] of Cape Horn, makes this one of the world's centers of whal[illegible]ing. On the west coast of the United States the catch of sardin[illegible] is sometimes a much as billion pounds in a year supporting one of the largest fisheries in the world. The fishery could not exist except for upwelling which sets off the old, familiar bio[illegible]logical chain, salts, diatoms, copepods, herring. Down along the west coast of South America the astonishing profusion of lif[illegible] in the Humboldt maintained by upwelling, which not only

From Natural History, vol 13 no. 8, 19[illegible] p. 356.

keeps the waters of the current cold in all its 2500-mile course to the Galapagos Islands but brings up the nutrient salts from the deeper layers.

When upwelling takes place along coastlines, it is the result of the interplay of several forces—the winds, the surface currents, the rotation of the earth, and the shape of the hidden slopes of the continent's foundations. When the winds, combined with the deflecting effect of rotation, blow the surface waters offshore, deep water must rise to replace it.

Upwelling may occur in the open sea as well, but from entirely different causes. Wherever two strongly moving currents diverge, water must rise from below to fill the place where the streams separate. One such place lies at the westernmost bounds of the Equatorial Current in the Pacific, where the powerfully moving stream turns and pours part of its waters back into the countercurrent, and part northward toward Japan. These are confused and turbulent waters. There is the strong pull to the north by which the main stream, sensitive to the force of the rotating earth, turns to the right. There are the swirls and eddies by which the lesser stream turns again upon itself and flows back into the eastern Pacific. There is the rushing up from below to fill the otherwise deepening groove between the streams. In the resulting disquietude of the ocean waters, chilled and enriched from below the smaller organisms of the plankton thrive. As they multiply they provide food for the larger plankton creatures, which, in turn, provide food for squid and fish. These waters are prodigiously rich in life, and there is evidence that they may have been so for many thousands of years. Swedish oceanographers recently found that under these areas of divergence the sediment layer is exceptionally thick—the layer composed of all that remains of the billions upon billions of minute creatures that have lived and died in this place.

The downward movement of surface water into the depths is an occurrence as dramatic as upwelling, and perhaps it fills the human mind with an even greater sense of we and mystery, because it cannot be seen but can only be imagined. At several known places the downward flow of enormous quantities of water takes place regularly This water feeds the deep currents of whose courses we have only the dimmest knowledge. We do know that it is all part of the ocean s system of balances, by which she pays back to one part of her waters what she had latterly borrowed for distribution to another

The North Atlantic, for example, receives quantities of surface water (some 6 million cubic meters second) from the South Atlantic via the Equatorial Current. The return payment is made at deep levels, partly in very cold arctic water and partly in some of the saltiest, warmest water in the world, that

of the Mediterranean. There are two places for the down of arctic water. One is in the Labrador Sea. Another is east of Greenland. At each the quantity of sinking water prodigious—some 2 million cubic meters a second. The Mediterranean water flows out over the sill that separates basin of the Mediterranean from the open Atlantic. This lies about 150 f thoms beneath the surface of the sea. water that spills over its rocky edge does so because of the usual conditions that prevail in the Mediterranean. The sun beating down on its nearly enclosed water creates an e ordinarily high rate of evaporation, drawing off into the mosphere more water than is added by the inflow of rivers. water becomes ever saltier and more dense as evaporation continues the surface of the Mediterranean falls below that the Atlantic. To correct the inequality lighter water from Atlantic pours past Gibraltar in surface streams of strength.

Now we give the matter little thought, but in the days of passage out into the Atl ntic was difficult problem because this surface current. An old ship s log of the year 1855 has to say of the current and its practical effect

'Weather fine made 1¼ pt. leeway At noon, stood in Almira Bay and anchored off the village of Roguetas. Foun great number of vessels waiting for a chance to get to the we ward, and learned from them that at least a thousand sail weather-bound between this and Gibraltar Some of them ha been so for six weeks, and have even got so f r as Malaga, on to be swept back by the current. Indeed, no vessel has bee able to get out into the Atlantic for three months past.

*Later measurements show that these surface currents fl* into the Mediterranean with an average velocity of about knots. The bottom current, moving out into the Atlantic, is ev stronger Its outward flow is so vigorous that it has been know *to wreck oceanographic instruments sent down to measure it*, apparently pounding them against stones on the bottom and once the wire of the Falmouth cable near Gibraltar 'was ground like the edge of a razor so that it had to be abandoned and new one laid well inshore.

The water that sinks in the arctic regions of the Atlantic, as well as that spilling over the Gibraltar sill, spreads out widely into the deeper parts of the ocean basins. Traversing the North Atlantic, it crosses the *equator and continues to the south*, there passing between two layers of water that are mo ... from the Antarctic Sea. Some of this antar with the Atlantic water—that from Greenl,. and the Mediterranean—and with it return

antarctic water moves northward across the equator and has been traced as far as the latitude of Cape Hatteras.

The flow of these deep waters is hardly a 'flow' at all. Its pace is ponderously slow—the measured creep of icy, heavy water. But the volumes involved are prodigious, and the areas covered world-wide. It may even be that the deep ocean water, on such global wanderings, acts to distribute some of the marine fauna—not the surface forms but the dwellers in deep, dark layers. From our knowledge of the source of the currents, it seems significant that some of the same species of deep-water invertebrates and fishes have been collected off the coast of South Africa and off Greenland. And about Bermuda, where a greater variety of deep water forms has been found than anywhere else, there is a mingling of deep water from the Antarctic, the Arctic, and the Mediterranean. Perhaps in these sunless streams the weird inhabitants of deep waters drift, generation after generation, surviving and multiplying because of the almost changeless character of these slowly moving currents.

There is, then, no water that is wholly of the Pacific, or wholly of the Atlantic, or of the Indian or the Antarctic. The surf that we find exhilarating at Virginia Beach or at La Jolla today may have lapped at the base of antarctic icebergs or sparkled in the Mediterranean sun, years ago, before it moved through dark and unseen waterways to the place we find it now. It is by the deep, hidden currents that the oceans are made one.

## 11 The Moving Tides

*In every country the moon keeps ever the rule of alliance with the sea which it once for all has agreed upon.*

THE VENERABLE BEDE

THERE is no drop of water in the ocean, not even in the deepest parts of the abyss, that does not know and respond to the mysterious forces that create the tide. No other force that affects the sea is so strong. Compared with the tide the wind-created waves are surface movements felt, at most, no more than a hundred fathoms below the surface. So, despite their impressive sweep, are the planetary currents, which seldom involve more than the upper several hundred fathoms. The masses of water affected by the tidal movement are enormous, as will be clear from one example. Into one small bay on the east coast of North America—Passamaquoddy—2 billion tons of water are carried by the tidal current twice each day; into the whole Bay of Fundy, 100 billion tons.

Here and there we find dramatic illustration of the the tides affect the whole ocean, from its surface to its The meeting of opposing tidal currents in the Strait of creates whirlpools (one of them is Charybdis of classical which so deeply stirs the waters of the strait that fish the marks of abyssal existence, their eyes atrophied or mally large, their bodies studded with phosphor frequently are cast up on the lighthouse beach, and the area yields a rich collection of deep-sea fauna for the of Marine Biology at Messina.

The tides are a response of the mobile waters of the the pull of the moon and the more distant sun. In theory is a gravitational attraction between every drop of sea and even the outermost star of the universe. In practi- ever the pull of the remote stars is so slight as to be obl in the vaster movements by which the ocean yields to the and the sun. Anyone who has lived near tidewater that the moon, far more than the sun, controls the tides. He noticed that, just as the moon rises later each day by fifty utes, on the average, than the day before, so, in most p time of high tide is correspondingly later each day. And as moon waxes and wanes in its monthly cycle, so the height tide varies. Twice each month, when the moon is a thread of silver in the sky and again when it is full, we the strongest tidal movements—the highest flood tides and lowest ebb tides of the lunar month. These are called the tides. At these times sun, moon, and earth are directly in and the pull of the two heavenly bodies is added bring the water high on the beaches, and send its surf leapi upward against the sea cliffs, and draw a brimming tide the harbors so that the boats float high beside their wharfs. twice each month, at the quarters of the moon, when sun, and earth lie at the apexes of a triangle, and the pull and moon are opposed, we have the moderate tidal called the neap tides. Then the difference between high low water is less than at any other time during the month.

That the sun, with a mass 27 million times that o should have less influence over the tides than a small satellite of the earth is at first surprising. But in the mechanics of the uni- verse, nearness counts for more than distant mass, and when all the mathematical calculations have been made we find that the moon's power over the tides is more than twice that of the sun.

The tides are enormously more complicated than all this would suggest. The influence of sun and moon is cons changing, varying with the phases of the moon, with the d tance of moon and sun from the earth, and with the position of each to north or south of the equator. They are complicated

further by the fact that every body of water, whether natural or artificial, has its own period of oscillation. Disturb its waters and they will move with a seesaw or rocking motion, with the most pronounced movement at the ends of the container the least motion at the center. Tidal scientists now believe that the ocean contains a number of "basins, each with its own period of oscillation determined by its length and depth. The disturbance that sets the water in motion is the attracting force of the moon and sun. But the kind of motion, that is, the period of the swing of the water depends upon the physical dimensions of the basin. What this means in terms of actual tides we shall presently see.

The tides present a striking paradox, and the essence of it is this: the force that sets them in motion is cosmic, lying wholly outside the earth and presumably acting impartially on all parts of the globe, but the nature of the tide at any particular place is a local matter with astonishing differences occurring within a very short geographic distance. When we spend a long summer holiday at the seashore we may become aware that the tide in our cove behaves very differently from that at a friend's place twenty miles up the coast, and is strikingly different from what we may have known in some other locality. If we are summering on Nantucket Island our boating and swimming will be little disturbed by the tides, for the range between high water and low is only about a foot or two. But if we choose to vacation near the upper part of the Bay of Fundy we must accommodate ourselves to rise and fall of 40 to 50 feet, although both places are included within the same body of water—the Gulf of Maine. Or if we spend our holiday on Chesapeake Bay we may find that the time of high water each day varies by as much as 12 hours in different places on the shores of the same bay.

The truth of the matter is that local topography is all-important in determining the features that to our minds mak the tide. The attractive force of the heavenly bodies sets the water in motion, but how and how far and how strongly it will rise depend on such things as the slope of the bottom, the depth of a channel, or the width of a bay's entrance.

The United States Coast and Geodetic Survey has remarkable robotlik machine with which it can predict the time and height of the tide on any past or future date, for any part of the world, on one essential condition. This is that at some time local observations must have been made to show how the topographic features of the place modify and direct the tidal movements.

Perhaps the most striking differences are in the range of tide which rise tremendously in different parts of the world, so that what the inhabitants of one place might consider

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12 hours. This very nearly coincides with the period of the ocean tide. Therefore the water movement within the bay is sustained and enormously increased by the ocean tide. The narrowing and shallowing of the bay in its upper reaches, compelling the huge masses of water to crowd into a constantly diminishing area, also contribute to the great heights of the Fundy tides.

The tidal rhythms, as well as the range of tide, vary from ocean to ocean. Flood tide and ebb succeed each other around the world, as night follows day but as to whether there shall be two high tides and two low in each lunar day or only one, there is no unvarying rule. To those who know best the Atlantic Ocean—either its eastern or western shores—the rhythm of two high tides and two low tides in each day seems 'normal. Here, on each flood tide, the water advances about as far as on the preceding high, and succeeding ebb tides fall about equally low But in that great inland sea of the Atlantic, the Gulf of Mexico, a different rhythm prevails around most of its borders. At best the tidal rise here is but a slight movement, of no more than a foot or two. At certain places on the shores of the Gulf it is a long, deliberate undulation—one rise and one fall in the lunar day of 24 hours plus 50 minutes—resembling the untroubled breathing of that earth monster to whom the ancients attributed all tides. This diurnal rhythm is found in scattered places about the earth—such as at Saint Michael, Alaska, and at Do Son in French Indo-China—as well as in the Gulf of Mexico. By far the greater part of the world's coasts—most of the Pacific basin and the shores of the Indian Ocean—display a mixture of the diurnal and semi-diurnal types of tides. There are two high and two low tides in day but the succeeding floods may be so unequal that the second scarcely rises to mean sea level, or it may be the ebb tides that are of extreme inequality

There seems to be no simple explanation of why some parts of the ocean should respond to the pull of sun and moon with one rhythm and other parts with another although the matter is perfectly clear to tidal scientists on the basis of mathematical calculations. To gain some taking of the reasons, we must recall the many separate component of the tide-producing force, which in turn result from the *changing relative positions* of sun, moon, and earth. Depending on local geographic f atures, every part of earth and sea, while affected in some degree by each component, is more responsive to some than to others. Presumably the shape and depths of the Atlantic basin cause it to respond most strongly to the forces that produce a semi rhythm. The Pacific and Indian oceans, on the

has the fishes. But over the millions of years the moon has receded, driven away by the friction of the tide it creates. The very movement of the water over the bed of the ocean, over the shallow edges of the continents, and over the inland seas carries within itself the power that is slowly destroying the tides, for tidal friction is gradually slowing down the rotation of the earth. In those early days we have spoken of, it took the earth a much shorter time—perhaps only about 4 hours—to make a complete rotation on its axis. Since then, the spinning of the globe has been so greatly slowed that a rotation now requires, as everyone knows, about 24 hours. This retarding will continue, according to mathematicians, until the day is about 50 times as long as it is now

And all the while the tidal friction will be exerting a second effect, pushing the moon farther away just as it has already pushed it out more than 200,000 miles. (According to the laws of mechanics, as the rotation of the earth is retarded, that of the moon must be accelerated, and centrifugal force will carry it farther away ) As the moon recedes, it will, of course, have less power over the tides and they will grow weaker It will also take the moon longer to complete its orbit around the earth. When finally the length of the day and of the month coincide, the moon will no longer rotate relatively to the earth, and there will be no lunar tides.

All this, of course, will require time on a scale the mind finds it difficult to conceive, and before it happens it is quite probable that the human race will have vanished from the earth. This may seem, then, like a Wellsian fantasy of a world so remote that we may dismiss it from our thoughts. But already even in our allotted fraction of earthly time, we can see some of the effects of these cosmic processes. Our day is believed to be several seconds longer than that of Babylonian times. Britain Astronomer Royal recently called the attention of the American Philosophical Society to the fact that the world will soon have to choose between two kinds of time. The tide-induced lengthening of the day has already complicated the problems of human systems of keeping time. Conventional clocks, geared to the earth's rotation, do not show the effect of the lengthening [illegible] New atomic clocks now being constructed will show [illegible] and will differ from other clocks.

Although the tides have become tamer and their [illegible] now measured in tens instead of hundreds of feet, [illegible] nevertheless greatly concerned not only with the [illegible] tide and the set of the tidal currents, but with the [illegible] movements and disturbances of the sea that are [illegible] lated to the tides. Nothing the human mind has [illegible] tame tide up or control the rhythm of the [illegible]

stem, its noisy *bubbling and boiling, until suddenly the whirlpool* was formed before his eyes and rushed with an appalling sound through the narrow waterway. Then the old man told the story of his own descent into the whirlpool and of his miraculous escape. Most of us have wondered how much of the story was fact, how much the creation of Poe's fertile imagination. There actually is a Maelstrom and it exists where Poe placed it, between two of the islands of the Lofoten group off the west coast of Norway. *It is, as he described it, a gigantic whirlpool* or series of whirlpools, and men with their boats have actually been drawn down into these spinning funnels of water. Although Poe's account exaggerates certain details, the essential facts on which he based his narrative are verified in the *Sailing Directions for the Northwest and North Coasts of Norway*, a practical and circumstantial document:

Though rumor has greatly exaggerated the importance of the Malström, *or more properly Moskenstraumen, which runs* between Mosken and Lofotodden, it is still the most dangerous tideway in Lofoten, its violence being due, in great measure, to the irregularity of the ground .... As the strength of the tide increases the sea becomes heavier and the current more irregular, forming extensive eddies or whirlpools (Malstrøm). During such periods no vessel should enter the Moskenstraumen.

These whirlpools are cavities in the form of an inverted bell, wide and rounded at *the mouth and narrowed toward* the bottom; they are largest when first formed and are carried along with the current, diminishing gradually until they disappear; *before the extinction of* one, two or three more will appear, following each other like so many pits in the sea .... Fishermen affirm that if they are aware of their approach to a whirlpool and have time to throw an oar or any other bulky body into it they will get over it safely; the reason is that when the continuity is broken and the whirling motion of the sea interrupted by something thrown into it the water must rush suddenl... on all sides and fill up the cavity. For the same reason ... strong breezes, when the w...ves break, though there m... he ... hirling round, there ca... be no cavity. In the Saltstrom boat... d men have been drawn down by these vortices, and much loss of life has resulted.

Among unusual creations of the tide, perhaps ... he best known are the bores. The world possesses half a dozen ... r more famous ones. A bore is created when a great part of the fl... d tide enters river as ... single wave, or at most two or three ... ves, with steep and high front. The conditions that produ... bores are several: there must be ... considerable range of tide, combined with sand bars or other obstructions in the mouth of the ... that the tide is hindered and held back, until a fear...

spring tides, which are about two days after the full or the new moon. In the waters of northern Africa there is a sea urchin that, on the nights when the moon is full and apparently only then, releases its reproductive cells into the sea. And in tropical waters in many parts of the world there are small marine worms whose spawning behavior is so precisely adjusted to the tidal calendar that, merely from observing them, one could tell the month, the day and often the time of day as well.

Near Samoa in the Pacific, the palolo worm lives out its life on the bottom of the shallow sea, in holes in the rocks and among the masses of corals. Twice each year during the neap tides of the moon's last quarter in October and November the worms forsake their burrows and rise to the surface in swarms that cover the water For this purpose, each worm has literally broken its body in two half to remain in its rock tunnel, half to carry the reproductive products to the surface and there to liberate the cells. This happens at dawn on the day before the moon reaches its last quarter and again on the following day on the second day of the spawning the quantity of eggs liberated is so great that the sea is discolored.

The Fijians, whose waters have similar worm, call them 'Mbalolo and have designated the periods of their spawning Mbalolo lailai' (little) for October and 'Mbalolo levu' (large) for November Similar forms near the Gilbert Islands respond to certain phases of the moon in June and July in the Malay Archipelago a related worm swarms at the surface on the second and third night after the full moon of March and April, when the tides are running highest. A Japanese palolo swarms after the new moon and again after the full moon in October and November

Concerning each of these, the question recurs but remains unanswered Is it the state of the tides that in some unknown way supplies the impulse from which springs this behavior or is it, even more mysteriously some other influence of the moon? It is easier to imagine that it is the press and the rhythmic movement of the water that in some way brings about this response. But why is it only certain tides of the year and why for some species is it the fullest tides of the month and for others the least movements of the waters that are related to the perpetuation of the race? At present, no one ca answer

No other creature displays so exquisite an adapt tion to the tidal rhythm as the grunion—a small, shimmering fish bout as long a man's hand. Through no one can say what processes of adaptation, extending over no one know how many millennia, the grunion has come to know not only the daily rhythm of the tides, but the monthly cycle by which certain tides sweep hi on the beaches than others. It has so

deep sands of the intertidal zone as soon as the tide has ebbed, the sand becoming spotted with large green patches composed of thousands of the worms. For the several hours while the tide is out, the worms lie thus in the sun, and the plants manufacture their starches and sugars; but when the tide returns, the worms must again sink into the sand to avoid being washed away out into deep water. So the whole lifetime of the worm is a succession of movements conditioned by the stages of the tide—upward into sunshine on the ebb, downward on the flood.

What I find most unforgettable about Convoluta is this: sometimes it happens that a marine biologist, wishing to study some related problem, will transfer a whole colony of the worms into the laboratory, there to establish them in an aquarium, where there are no tides. But twice each day Convoluta rises out of the sand on the bottom of the aquarium, into the light of the sun. And twice each day it sinks again into the sand. Without a brain, or what we would call a memory, or even any very clear perception, Convoluta continues to live out its life in this alien place, remembering, in every fiber of its small green body, the tidal rhythm of the distant sea.

when Stream temperatures were above normal, was long remembered for its cold and snowy weather along the east coast. If we could move the Stream inshore, the result in winter would be colder, stronger winds from the interior of the continent—not milder weather.

But if the eastern North American climate is not dominated by the Gulf Stream, it is far otherwise for the lands lying downstream. From the Newfoundland Banks, as we have seen, the warm water of the Stream drifts eastward, pushed along by the prevailing westerly winds. Almost immediately however it divides into several branches. One flows north to the western shore of Greenland, there the warm water attacks the ice brought around Cape Farewell by the East Greenland Current. Another passes to the southwest coast of Iceland and, before losing itself in arctic waters, brings a gentling influence to the southern shores of that island. But the main branch of the Gulf Stream or North Atlantic Drift flows eastward. Soon it divides again. The southernmost of these branches turns toward Spain and Africa and re-enters the Equatorial Current. The northernmost branch, hurried eastward by the winds blowing around the Icelandic "low" piles up against the coast of Europe the warmest water found at comparable latitudes anywhere in the world. From the Bay of Biscay north its influence is felt. And as the current rolls northeastward along the Scandinavian coast, it sends off many lateral branches that curve back westward to bring the breath of warm water to the arctic islands and to mingle with other currents in intricate whirls and eddies. The west coast of Spitsbergen, warmed by one of these lateral streams, is bright with flowers in the arctic summer: the east coast, with its polar current, remains barren and forbidding. Passing around the North Cape, the warm currents keep open such harbors as Hammerfest and Murmansk, although Riga, 800 miles farther south on the shores of the Baltic, is choked with ice. Somewhere in the Arctic Sea, near the island of Novaya Zemlya, the last traces of Atlantic water disappear losing themselves at last in the overwhelming sweep of the icy northern sea.

It is always a warm-water current, but the temperature of the Gulf Stream nevertheless varies from year to year and seemingly slight change profoundly affects the air temperatures of Europe. The British meteorologist, C. E. P. Brooks, compares the North Atlantic to a great bath, with hot tap and two cold taps. The hot tap is the Gulf Stream the cold taps are the East Greenland Current and the Labrador Current. Both the volume and the temperature of the hot-water tap vary. The cold taps are nearly constant in temperature but vary immensely in volume. The adjustment of the three taps determines surf

bring variable pressure to bear on the surface of the sea, which is depressed under areas of high pressure and springs up in compensation under the atmospheric lows. With the moving force of the winds, the air grips the surface of the ocean and raises it into waves, drives the currents onward, lowers sea level on windward shores, and raises it on lee shores.

But even more does the ocean dominate the air. Its effect on the temperature and *humidity* of the atmosphere is far greater than the small transfer of heat from air to sea. It takes 3000 times as much heat to warm a given volume of water 1° as to warm an equal volume of air by the same amount. The heat lost by a cubic meter of water on cooling 1° C. would raise the temperature of 3000 cubic meters of air by the same amount. Or to use another example, a layer of water a meter deep, on cooling 1° could warm a layer of air 33 meters thick by 10°. The temperature of the air is intimately related to atmospheric pressure. Where the air is cold, pressure tends to be high; warm air favors low pressures. The transfer of heat between ocean and air therefore alters the belt of high and low pressure; this profoundly affects the direction and strength of the winds and directs the storms on their paths.

There are six more or less permanent centers of high pressure over the oceans, three in each hemisphere. Not only do these areas play a controlling part in the climate of surrounding lands, but they affect the whole world because they are the birthplaces of most of the dominant winds of the globe. The trade winds originate in high-pressure belts of the Northern and Southern hemispheres. Over all the vast extent of ocean across which they blow, these great winds retain their identity; it is only over the continents that they become interrupted, confused, and modified.

In other ocean areas there are belts of low pressure, which develop especially in winter over waters that are then warmer than the surrounding lands. Traveling barometric depressions or cyclonic storms are attracted by these areas, they move rapidly across them or skirt around their edges. So winter storms take a path across the Icelandic 'low' and over the Shetlands and Orkneys into the North Sea and the Norwegian Sea, other storms are directed by still other low-pressure areas over the Skagerrak and the Baltic into the interior of Europe. Perhaps more than any other condition, the low-pressure area over the warm water south of Iceland dominates the winter climate of Europe.

And most of the rains that fall on sea and land alike were raised from the sea. They are carried as vapor in the winds, then with change of temperature the rains fall. Most European rain comes from evaporation of Atlantic

the United States, vapor and warm air from the Gulf of and the tropical waters of the western Atlantic ride the up the wide valley of the Mississippi and provide rains of the eastern part of North America.

Whether any place will know the harsh extremes of nental climate or the moderating effect of the sea depends l on its nearness to the ocean than on the pattern of winds and the relief of the continents. The east coast of America receives little benefit from the sea, because the pre ing winds are from the west. The Pacific coast, on the hand, lies in the path of the westerly winds that have bl across thousands of miles of ocean. The moist breath of Pacific brings climatic mildness and creates the dense ests of British Columbia, Washington, and Oregon but its influence is largely restricted to a narrow strip by the ranges that follow a course parallel to the sea. Europe, in trast, is wide open to the sea, and Atlantic weather' hundreds of miles into the interior

By a seeming paradox, there are parts of the world that c their desert dryness to their nearness to the ocean. The of the Atacama and Kalahari deserts is curiously related to sea. Wherever such marine deserts occur there is found combination of circumstances a western coast in the path the prevailing winds, and a cold coastwise current. So on west coast of South America the cold Humboldt streams ward off the shores of Chile and Peru—the great return Pacific waters seeking the equator The Humboldt, it will remembered, is cold because it is continuously being rei, by the upwelling of deeper water The presence of this water offshore helps create the aridity of the region. T shore breezes that push in toward the hot land in the are formed of cool air that has lain over a cool sea. As reach the land they are forced to rise into the high coastal tains—the ascent cooling them more than the land can them. So there is little condensation of water vapor and though the cloud banks and the fogs forever seem to , rain, the promise is not fulfilled so long as the Humboldt on its accustomed course along these shores. On the from Arica to Caldera there is normally less than an inch of rain in a year It is a beautifully balanced system—as long as it remains in balance. What happens when the Humboldt is porarily displaced is nothing short of catastrophic.

At irregular intervals the Humboldt is deflected away from the South American continent by a warm current of tropical water that comes down from the north. These are years of di- aster The whole economy of the area is adjusted to the normal aridity of climate. In the years of El Niño, as the warm current

is called, torrential rains fall—the downpouring rains of the equatorial regions let loose upon the dust-dry hillsides of the Peruvian coast. The soil washes away the mud huts literally dissolve and collapse, crops are destroyed. Even worse things happen at sea. The cold-water fauna of the Humboldt sickens and dies in the warm water and the birds that fish the cold sea for a living must either migrate or starve.

Those parts of the coast of Africa that are bathed by the cool Benguela Current also lie between mountains and sea. The easterly winds are dry descending winds, and the cool breezes from the sea have their moisture capacity increased by contact with the hot land. Mists form over the cold waters and roll in over the coast, but in a whole year the rainfall is the meagerest token. The mean rainfall at Swakopmund in Walvis Bay is 0 7 inches a year But gain this is true only as long as the Benguela holds sway along the coast, for there are times when the cold stream falters as does the Humboldt, and here also these are years of disaster

The transforming influence of the sea is portrayed with beautiful clarity in the striking differences between the Arctic and Antarctic regions. As everyone knows, the Arctic is a nearly landlocked sea the Antarctic, a continent surrounded by ocean. Whether this global balancing of a land pole against a water pole has a deep significance in the physics of the earth is uncertain but the bearing of the fact on the climates of the two regions is plainly evident.

The ice-covered Antarctic continent, bathed by seas of uniform coldness, is in the grip of the polar anticyclone. High winds blow from the land and repel any warming influence that might seek to penetrate it. The mean temperature of this bitter world is never above the freezing point. On exposed rocks the lichens grow covering the barrenness of cliff with their gray or orange growths, and here and there over the snow is the red dust of the hardier algae. Mosses hide in the valley nd crevices less exposed to the winds, but of the higher plants only few impoverished stands of grasses have managed to invade this land. There are no land mammals, the f una of the Antarctic continent consist only of birds, w ngless mosquitoes, few flies, and microscopic mites.

I sharp contrast are the arctic summers, where the tundra is bright with many-colored flowers. Everywhere except on the Greenland icecap and some of the arctic islands, summer temperatures are high enough for the growth of plants, packing year' des lopment into the short, warm, rctic summer The polar limit of plant growth is set not by latitude but by the sea. For the influence of the warm Atlantic penetrates strong within the Arctic Sea, entering, as w hav seen, thro

Some of these deep waves of the Gulmarfiord were giants nearly 100 feet high. Pettersson believed they were formed by the impact of the oceanic tide wave on the submarine ridges of the North Atlantic, as though the waters moving to the pull of the sun and moon, far down in the lower levels of the sea, broke and spilled over in mountains of highly saline water to enter the fiords and sounds of the coast.

From the submarine tide waves, Pettersson mind moved logically to another problem—the changing fortunes of the Swedish herring fishery His native Bohuslan had been the site of the great Hanseatic herring fisheries of the Middle Ages. All through the thirteenth, fourteenth, and fifteenth centuries this great sea fishery was pursued in the Sund and the Belts, the narrow passageways into the Baltic. The towns of Skanor and Falsterbo knew unheard-of prosperity for there seemed no end of the silvery wealth-bringing fish. Then suddenly the fishery ceased, for the herring withdrew into the North Sea and came no more into the gateways of the Baltic—this to the enrichment of Holland and the impoverishment of Sweden. Why did the herring cease to come? Pettersson thought he knew and the reason was intimately related to that moving pen in his laboratory, the pen that traced on a revolving drum the movements of the submarine waves far down in the depths of Gulmarfiord.

He had found that the submarine waves varied in height and power as the tide-producing power of the moon and sun varied. From astronomical calculations he learned that the tides must have been at their greatest strength during the closing centuries of the Middle Ages—those centuries when the Baltic herring fishery was flourishing. Then sun, moon, and earth came into such position at the time of the winter solstice that they exerted the greatest possible attracting force upon the sea. Only about every eighteen centuries do the heavenly bodies assume this particular relation. But in that period of the Middle Ages, the great underw ter waves pressed with unusual force into the narrow passages to the Baltic, *and with the 'water mountains'* went the herring boals. Later when the tides became weaker the herring remained outside the Baltic, in the North Sea.

Then Pettersson realized another fact of extreme significance—that those centuries of great tides had been period of 'startling and unusual occurrences in the world t ture Polar ice blocked much of the North Atlantic The coast of the North Sea and the B ltic were laid wast by violent storm floods. The winters were of 'unexampled severity' and in consequence the climatic rigors political and economic catastrophes curred all over the populated regions of the earth. C

the villages mentioned in the old records. But its excavations indicated clearly that the colonists lived in a climate definitely milder than the present one.

But these bland climatic conditions began to deteriorate in the thirteenth century. The Eskimos began to make [illegible] raids, perhaps because their northern sealing grounds were frozen over and they were hungry. They attacked the western settlement near the present Ameralik Fiord, and when an official mission went out from the eastern colony about 1342, not a single colonist could be found—only a few cattle [illegible]. The eastern settlement was wiped out some time after [illegible] and the houses and churches destroyed by fire. Perhaps the fate of the Greenland colonies was in part due to the fact that ships from Iceland and Europe were finding it increasingly difficult to reach Greenland, and the colonists had to be left to their own resources.

The climatic rigors experienced in Greenland in the thirteenth and fourteenth centuries were felt also in Europe in a series of unusual events and extraordinary catastrophes. The seacoast of Holland was devastated by storm floods. Old Icelandic records say that, in the winters of the early [illegible], packs of wolves crossed on the ice from Norway to Denmark. The entire Baltic froze over, forming a bridge of solid ice between Sweden and the Danish islands. Pedestrians and carriages crossed the frozen sea and hostelries were put up on the ice to accommodate them. The freezing of the Baltic seems to have shifted the course of storms originating in the low-pressure [illegible] south of Iceland. In southern Europe, as a result, there were unusual storms, crop failures, famine, and distress. [illegible] literature abounds in tales of volcanic eruptions and other violent natural catastrophes that occurred during the fourteenth century.

What of the previous era of cold and storm, which should have occurred about the third or fourth century [illegible] to the tidal theory? There are shadowy hints in early [illegible] and folklore. The dark and brooding poetry of the [illegible] with a great catastrophe, the [illegible] merung, when frost and snow ruled the world for [illegible]. When Pytheas journeyed to the seas north of [illegible] B.C., he spoke of the mare pigrum, a [illegible]. Early history contains striking [illegible] movements of the tribes of northern Europe [illegible] migrations of the barbarians who [illegible] coincided with periods of storm [illegible] catastrophes had forced their [illegible] tions of the sea destroyed the [illegible] Cimbrians in Jutland and sent them [illegible]

tion among the Druids said that their ancestors had been pelled from their lands on the far side of the Rhine by tribes and by 'a great invasion of the ocean. And about the y 700 B.C. the trade routes for amber found on the coasts of North Sea, were suddenly shifted to the east. The old came down along the Elbe, the Weser and the the Brenner Pass to Italy The new route followed the suggesting that the source of supply was then the Baltic. haps storm floods had destroyed the earlier amber districts, they invaded these same regions eighteen centuries later

All these ancient records of climatic variations seemed Pettersson an indication that cyclic changes in the oceanl lation and in the conditions of the Atlantic had occurred. geologic alteration that could influence the climate has curred for the past six or seven centuries, he wrote. The nature of these phenomena—floods, inundations, ice bl —suggested to him a dislocation of the oceanic circulation plying the discoveries in his laboratory on Gulmarfiord, he lieved that the climatic changes were brought about as the ti submarine waves disturbed the deep waters of po seas. Although tidal movements are often weak at the these seas, they set up strong pulsations at the submarine aries, where there is a layer of comparatively fresh, cold w lying upon a layer of salty warmer water. In the years or centuries of strong tidal forces, unusual quantities of lantic water press into the Arctic Sea at deep levels, moving under the ice. Then thousands of square miles of ice that mally remain solidly frozen undergo partial thawing and up. Drift ice, in extraordinary volume, enters the I Current and is carried southward into the Atlantic. changes the pattern of surface circulation, which is so ly related to the winds, the rainfall, and the air For the drift ice then attacks the Gulf Stream south of foundland and sends it on a more easterly course, deflecting streams of warm surface water that usually bring a sof effect to the climate of Greenland, Iceland, Spitsbergen, and northern Europe. The position of the low-pressure belt south of Iceland is also shifted, with further direct effect on European climate.

Although the really catastrophic disturbances of the polar regime come only every eighteen centuries, according to Pettersson, there are also rhythmically occurring periods that fall at varying intervals—for example, every 9 18 or 36 years. These correspond to other tidal cycles. They produce climatic variations of shorter period and of less drastic nature.

The year 1903 for instance, was memorable for its out bursts of polar ice in the Arctic and for the repercussions on

Scandinavian fisheries. There was "a general failure of cod, herring, and other fish along the coast from Finmarken and Lofoten to the Skagerrak and Kattegat. The greater part of the Barents Sea was covered with pack ice up to May the ice border approaching closer to the Murman and Finmarken coasts than ever before. Herds of arctic seals visited these coasts, and some species of the arctic whitefish extended their migrations to the Christiania Fiord and even entered into the Baltic. This outbreak of ice came in a year when earth, moon, and sun were in a relative position that gives a secondary maximum of the tide-producing forces. The similar constellation of 1912 was another great ice year in the Labrador Current—a year that brought the disaster of the *Titanic*.

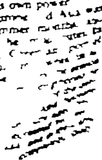
Now in our own lifetime we are witnessing a startling alteration of climate, and it is intriguing to apply Otto Pettersson's ideas as a possible explanation. It is now established beyond question that a definite change in the arctic climate set in about 1900, that it became astonishingly marked about 1930, and that it is now spreading into sub-arctic and temperate regions. The frigid top of the world is very clearly warming up.

The trend toward a milder climate in the Arctic is perhaps most strikingly apparent in the greater ease of navigation in the North Atlantic and the Arctic Sea. In 1932, for example, the *Knipowitsch* sailed around Franz Josef Land for the first time in the history of arctic voyaging. And three years later the Russian ice-breaker *Sadko* went from the northern tip of Novaya Zemlya to a point north of Severnaya Zemlya ... (Northern Land) and thence to 82° 41' north latitude—the northernmost point ever reached by a ship under its own power.

In 1940 the whole northern coast of Europe ... d Asia was remarkably free from ice during the summer ... more than 100 vessels engaged in trade via the ... 1942 a vessel unloaded supplies at the west C... Upernivik (latitude 72° 43' N) during Ch... most complete winter darkness. During ... for shipping coal from West Spitsbergen ... seven months compared with three at the ... tury. The season when pack ice lies ... shorter by about two months than it was ... ice in the Russian sector of the Arctic Se... bon square kilometers between 1924 an... tev Sea two islands of fossil ice melted ... position being marked by submarine ...

Activities in the northernmost world ... of the Arctic—the changed habits ... fishes, birds, land mammals, and whales ...

Many new birds are appearing in the ...



first time in our records. The long list of southern visitors—birds never reported in Greenland before 1920—includes the American velvet scoter the greater yellowlegs, American avocet, black-browed albatross, northern cliff swallow ovenbird, common crossbill, Baltimore oriole, and Canada warbler Some high-arctic forms, which thrive in cold climates, have shown their distaste for the warmer temperatures by visiting Greenland in sharply decreasing numbers. Such abstainers include the northern horned lark, the grey plover and the pectoral sandpiper Iceland, too, has an extraordinary number of boreal and even subtropical avian visitors since 1935 coming both from America and Europe. Wood warblers, skylarks, and Siberian rubythroats, scarlet grosbeaks, pipits, and thrushes now provide exciting fare for Icelandic bird watchers.

When the cod first appeared at Angmagssalik in Greenland in 1912, it was new and strange fish to the Eskimos and Within their memory it had never before appeared the east coast of the island. But they began to catch it, and the 1930's it supported so substantial a fishery in the area at the natives had become dependent upon it for food. They were also using its oil as fuel for their lamps and to heat their houses.

On the west coast of Greenland, too, the cod was a rarity the turn of the century although there was a small fishery ing about 500 tons a year at a few places on the southwest coast. About 1919 the cod began to move north along the west Greenland coast and to become more abundant. The center of the fishery has moved 300 miles farther north, and the catch is now about 15 000 tons a year

Other fishes seldom or never before reported in Greenland have appeared there. The coalfish or green cod is a European fish so foreign to Greenland waters that when two of them were caught in 1831 they were promptly preserved in salt and sent to the Copenhagen Zoological Museum. But since 1924 this fish has often been found among the cod shoals. The haddock, cusk, and ling, unknown in Greenland waters until about 1930, are now taken regularly Iceland, too, has strange visitors—warmth-loving southern fishes, like the basking shark, the grotesque sunfish, the six-gilled shark, the swordfish, and the horse mackerel. Some of these same species have penetrated into the Barents and White seas and along the Murman coast.

As the chill of the northern waters has abated and the fish have moved poleward, the fisheries around Iceland have expanded enormously and it has become profitable for trawlers to push on to Bear Island, Spitsbergen, and the Barents Sea. These waters now yield perhaps two billion pounds of cod a year—the largest catch of a single species by any fishery in the

world. But its existence is tenuous. If the cycle turns, the waters begin to chill, and the ice floes creep southward again, there is nothing man can do that will preserve the arctic fisheries.

But for the present, the evidence that the top of the world is growing warmer is to be found on every hand. The recession of the northern glaciers is going on at such a rate that many smaller ones have already disappeared. If the present rate of melting continues others will soon follow them.

The melting away of the snowfields in the Opdal Mountains in Norway has exposed wooden-shafted arrows of a type used about A.D. 400 to 500. This suggests that the snow cover in this region must now be less than it has been at any time within the past 1400 to 1500 years.

The glaciologist Hans Ahlmann reports that most Norwegian glaciers 'are living only on their own mass without receiving any annual fresh supply of snow'; that in the Alps there has been a general retreat and shrinkage of glaciers during the last decades, which became 'catastrophic' in the summer of 1947 and that all glaciers around the Northern Atlantic coasts are shrinking. The most rapid recession of all is occurring in Alaska, where the Muir Glacier receded about 10½ kilometers in 12 years.

At present the vast antarctic glaciers are an enigma, no one can say whether they also are melting away or at what rate. But reports from other parts of the world show that the northern glaciers are not the only ones that are receding. The glaciers of several East African high volcanoes have been diminishing since they were first studied in the 1800's—very rapidly since 1920—and there is a glacial shrinkage in the Andes and also in the high mountains of central Asia.

The milder arctic and sub-arctic climate seems already to have resulted in longer growing seasons and better crops. The cultivation of oats has improved in Iceland. In Norway good seed years are now the rule rather than the exception, and even in northern Scandinavia the trees have spread rapidly above their former timber lines, and both pine and spruce are making a quicker annual growth than they have for some time.

The countries where the most striking changes are taking place are those whose climate is most directly under the control of the North Atlantic currents. Greenland, Iceland, Spitsbergen, and all of northern Europe, as we have seen, experience heat and cold, drought and flood in accordance with the varying strength and warmth of the eastward and northward-moving currents of the Atlantic. Oceanographers who have been studying the matter during the 1940's have discovered significant changes in the temperature and distribution of masses of ocean water. Apparently the

Stream that flows past Spitsbergen has so increased in that it now brings in a great body of warm water waters of the North Atlantic show rising temperatures to the deeper layers around Iceland and Spitsbergen. Sea tures in the North Sea and along the coast of Norway been growing warmer since the 1920's.

Unquestionably there are other agents at work in about the climatic changes in the Arctic and sub-Arctic reg For one thing, it is almost certainly true that we are still in warming-up stage following the last Pleistocene glaciat that the world's climate, over the next thousands of years, wi grow considerably warmer before beginning a downward sw into another Ice Age. But what we are experiencing now perhaps a climatic change of shorter duration, measurable in decades or centuries. Some scientists say that there must been a small increase in solar activity changing the pattern air circulation and causing the southerly winds to blow frequently in Scandinavia and Spitsbergen changes in –, according to this view are secondary effects of of prevailing winds.

But if, as Professor Brooks thinks, the Pettersson tidal has as good a foundation as that of changing solar radiatior then it is interesting to calculate where our twentie situation fits into the cosmic scheme of the shifting cycles the tides. The great tides at the close of the Middle Ages, wi their accompanying snow and ice, furious winds, and inun dating floods, are more than five centuries behind us. The era of weakest tidal movements, with a climate as benign as that of the early Middle Ages, is about four centuries ahead. We have therefore begun to move strongly into a period of warmer milder weather There will be fluctuations, as earth and sun and moon move through space and the tidal power waxes and wanes. But the long trend is toward a warmer earth the pendu lum is swinging.

## 13 Wealth from the Salt Seas

*A sea change into something rich and strange.*
SHAKESPEARE

THE OCEAN is the earth s greatest storehouse of minerals. In a single cubic mile of sea water there are on the average 166 million tons of dissolved salts, and in all the ocean waters of the earth there are about 50 quadrillion tons. And it is in the nature of things for this quantity to be gradually increasing

over the millennia, for although the earth is constantly shifting her component materials from place to place, the heaviest movements are forever seaward.

It has been assumed that the first seas were only faintly saline and that their saltiness has been growing over the eons of time. For the primary source of the ocean's salt is the rocky mantle of the continents. When those first rains came—the centuries-long rains that fell from the heavy clouds enveloping the young earth—they began the processes of wearing away the rocks and carrying their contained minerals to the sea. The annual flow of water seaward is believed to be about 6500 cubic miles, this inflow of river water adding to the ocean several billion tons of salts.

It is a curious fact that there is little similarity between the chemical composition of river water and that of sea water. The various elements are present in entirely different proportions. The rivers bring in four times as much calcium as chloride, for example, yet in the ocean the proportions are strongly reversed—46 times as much chloride as calcium. An important reason for the difference is that immense amounts of calcium salts are constantly being withdrawn from the sea water by marine animals and are used for building shells and skeletons—for the microscopic shells that house the foraminifera, for the massive structures of the coral reefs, and for the shells of oysters and clams and other mollusks. Another reason is the precipitation of calcium from sea water. There is a striking difference, too, in the silicon content of river and sea water—about 500 per cent greater in rivers than in the sea. The silica is required by diatoms to make their shells, and so the immense quantities brought in by rivers are largely utilized by these ubiquitous plants of the sea. Often there are exceptionally heavy growths of diatoms off the mouths of rivers. Because of the enormous total chemical requirements of all the fauna and flora of the sea, only a small part of the salts annually brought in by rivers goes to increasing the quantity of dissolved minerals in the water. The inequalities of chemical make-up are further reduced by reactions that are set in motion immediately the fresh water is discharged into the sea, and by the enormous disparities of volume between the incoming fresh water and the ocean.

There are other agencies by which minerals are added to the sea—from obscure sources buried deep within the earth. From every volcano chlorine and other gases escape into the atmosphere and are carried down in rain onto the surface of land and sea. Volcanic ash and rock bring up other materials. And all the submarine volcanoes, discharg

craters directly into the sea, pour in boron, chlorine, su and iodine.

All this is a one-way flow of minerals to the sea. Only to very limited extent is there any return of salts to the land. attempt to recover some of them directly by chemical ... tion and mining, and indirectly by harvesting the sea's pl and animals. There is another way in the long, recurring ... of the earth, by which the sea itself gives back to the land w it has received. This happens when the ocean waters rise the lands, deposit their sediments, and at last withdraw leav over the continent another layer of sedimentary rocks. contain some of the water and salts of the sea. But it is only temporary loan of minerals to the land and the return begins at once by way of the old, familiar channels— erosion, run-off to the rivers, transport to the sea.

There are other curious little exchanges of materials sea and land. While the process of evaporation, which water vapor into the air leaves most of the salts behind, surprising amount of salt does intrude itself into the 'phere and rides long distances on the wind. The so-call 'cyclic salt' is picked up by the winds from the spray of a cresting sea or breaking surf and is blown inland, then down in rain and returned by rivers to the ocean. These invisible particles of sea salt drifting in the atmosphere are, fact, one of the many forms of atmospheric nuclei around wh raindrops form. Areas nearest the sea, in general, receive most salt. Published figures have listed 24 to 36 pounds acre per year for England and more than 100 pounds for Brit. Guiana. But the most astounding example of large-scale transport of cyclic salts is furnished by Sam Salt Lake in northern India. It receives 3000 tons of salt a year carried to it on the hot dry monsoons of summer from sea, 400 miles away

The plants and animals of the sea are very much better chemists than men, and so far our own efforts to extract the mineral wealth of the sea have been feeble compared with those of lower forms of life. They have been able to find and to utilize elements present in such minute traces that human chemists could not detect their presence until, very recently highly refined methods of spectroscopic analysis were developed.

We did not know for example, that vanadium occurred in the sea until it was discovered in the blood of certain sluggish and sedentary sea creatures, the holothurians (of which sea cucumbers are an example) and the ascidians. Relatively huge quantities of cobalt are extracted by lobsters and mussels, and nickel is utilized by various mollusks, yet it is only w

recent years that we have been able to recover even traces of these elements. Copper is recoverable only as about a hundredth part in a million of sea water yet it helps to constitute the life blood of lobsters, entering into their respiratory pigments as iron does into human blood.

In contrast to the accomplishments of invertebrate chemists, we have so far had only limited success in extracting sea salts in quantities we can use for commercial purposes, despite their prodigious quantity and considerable variety. We have recovered about fifty of the known elements by chemical analysis, and shall perhaps find that all the others are there, when we can develop proper methods to discover them. Five salts predominate and are present in fixed proportions. As we would expect, sodium chloride is by far the most abundant, making up 77.8 per cent of the total salts; magnesium chloride follows, with 10.9 per cent; then magnesium sulphate, 4.7 per cent; calcium sulphate, 3.6 per cent; and potassium sulphate, 2.5 per cent. All others combined make up the remaining .5 per cent.

Of all the elements present in the sea, probably none has stirred men's dreams more than gold. It is there—in all the waters covering the greater part of the earth's surface—enough in total quantity to make every person in the world a millionaire. But how can the sea be made to yield it? The most determined attempt to wrest a substantial quantity of gold from ocean waters—and also the most complete study of the gold in sea water—was made by the German chemist Fritz Haber after the First World War. Haber conceived the idea of extracting enough gold from the sea to pay the German war debt and his dream resulted in the German South Atlantic Expedition of the *Meteor*. The *Meteor* was equipped with a laboratory and filtration plant, and between the years 1924 and 1928 the vessel crossed and recrossed the Atlantic, sampling the water. But the quantity found was less than had been expected, and the cost of extraction far greater than the value of the gold recovered. The practical economics of the matter are about as follows: in a cubic mile of sea water there is about $93,000,000 in gold and $8,500,000 in silver. But to treat this volume of water in a year would require the twice-daily filling and emptying of 200 tanks of water, each 500 feet square and 5 feet deep. Probably this is no greater feat, relatively, than is accomplished regularly by corals, sponges, and oysters, but by human standards it is not economically feasible.

Most mysterious, perhaps, of all substances in the sea is iodine. In sea water it is one of the scarcest of the ... difficult to detect and resisting exact analysis. Yet ... in almost every marine plant and animal.

certain seaweeds accumulate vast quantities of it. Apparent' the iodine in the sea is in a constant state of chemical c sometimes being oxidized, sometimes reduced, again en into organi combinations. There seem to be constant changes between air and sea, the iod no in some form ‖ being carried int the air in spray for the air at sea level tains detectable qua tities which decrease with altitude. F the time liv g th ngs first made iodine a part of the chemis of their tis ues, they seem to have become increasingly d pendent on it now we ourselves could not exist without it a regulator of the basal met bolism of our bodies, through thy oid gland which accumulates it

All commer l d ne was f rmerly obtained from se weeds then the deposit of crude t te of soda from the hi deserts f North Chile were disco ered Probably the or sourc f this m terial—c lled liche—was some histori sea filled w th m rine pet tion but that is a subje of ontrove Iodine obtained lso from brine deposits from the subt rr n w ters t oil bearing rocks—all rectly of m rine igin

A monopol on the w ld brom ne held by the where 99 pe t f t m w ci ent ted The tiny frac present in rock w rig ally depos ted ther by the sea. Fr w obt ned t f om the b ines l ft in subt rranean by prehistoric ocea now there ar large plants on the coasts—especiall the United States—which use ocean as their raw m t ial nd xtract the bromi e directly I to modern method of mmerci al p oduction of bromine w have high test g sol e for our ars The is a long list of o uses, includ ng he manufactur f sed tives, fire extingu photographic chemical dyestuffs, and chemical material

One of the oldest b om ne deri at es known to man Tyrian purpl wh h the Phoenicians made in their dyebor from the purpl sn l M r This snail may be linked m curious and wonde t l w s w th the p odigious and seeming unreasonabl qua t t es of b omin found today in the D Sea, which cont t estim t d, some 850 million tons of the chemical. The ent t on f bromine in Dead Sea water is 100 times tha the sea Appa ently the supply is con stantly renewed by nde gr und hot springs, which discharge into the bottom of the Se of G lilee which in turn sends its waters to the De d Se by w y of the River Jordan. Some authorities believe that the source of the bromine in the hot springs is a deposit t bill ons of ancient snails, laid down by the sea of a bygone age in str tum long since buried.

Magnesium is anothe mineral we now obtain by collecting

large volumes of ocean water and treating it with chemicals, although originally it was derived only from brines or from the treatment of such magnesium-containing rocks as dolomite, of which whole mountain ranges are composed. In a cubic mile of sea water there are about 4 million tons of magnesium. Since the direct extraction method was developed about 1941, production has increased enormously. It was magnesium from the sea that made possible the wartime growth of the aviation industry, for every airplane made in the United States (and in most other countries as well) contains about half a ton of magnesium metal. And it has innumerable uses in other industries where a light-weight metal is desired, besides its long-standing utility as an insulating material, and its use in printing inks, medicines, and toothpastes, and in such war implements as incendiary bombs, star shells, and tracer ammunition.

Wherever climate has permitted it, men have evaporated salt from sea water for many centuries. Under the burning sun of the tropics the ancient Greeks, Romans, and Egyptians harvested the salt men and animals everywhere must have in order to live. Even today in parts of the world that are hot and dry and where drying winds blow, solar evaporation of salt is practiced—on the shores of the Persian Gulf, in China, and Japan, in the Philippines, and on the coast of California and the alkali flats of Utah.

Here and there are natural basins where the action of sun and wind and sea combine to carry on evaporation of salt on a scale far greater than human industry could accomplish. Such a natural basin is the Rann of Cutch on the west coast of India. The Rann is a flat plain, some 60 by 185 miles, separated from the sea by the Island of Cutch. When the southwest monsoons blow, sea water is carried in by way of a channel to cover the plain. But in summer, in the season when the hot northeast monsoon blows from the desert, no more water enters, and that which is collected in pools over the plain evaporates [illegible] salt crust, in some places several feet thick.

Where the sea has come in over the land, laid down its deposits, and then withdrawn, there have been created reservoirs of chemicals, upon which we can draw with comparatively little trouble. Hidden deep under the surface of our earth are pools of "fossil salt water," the brine of ancient seas; fossil deserts, the salt of old seas that evaporated away under conditions of extreme heat and dryness; and layers of sedimentary rock in which were contained the organic sediments and the salts of the sea that deposited them.

During the Permian period, which was a [illegible] and dryness and widespread deserts, [illegible] over much of Europe, covering parts of

France, Germany and Poland. Rains came seldom and the of evaporation was high. The sea became exceedingly salty it began to deposit layers of salts. For a period covering sands of years, only gypsum was deposited, perhaps ing a time when water fresh from the ocean occasionally tered the inland sea to mix with its strong brine. A with the gypsum were thicker beds of salt. Later as its shrank and the sea grew still more concentrated, deposits potassium and magnesium sulphates were formed (this representing perhaps 500 years). Still later and perhaps another 500 years, there were laid down mixed potassium magnesium chlorides or carnallite. After the sea had [illegible] pletely evaporated, desert conditions prevailed, and soon [illegible] salt deposits were buried under sand. The richest beds [illegible] famous deposits of Stassfurt and Alsace toward the outski[rts] of the original area of the old sea (as, for example, in there are only beds of salt. The Stassfurt beds are feet thick; their springs of brine have been known since thirteenth century and the salts have been mined since seventeenth century.

At an even earlier geological period—the Silurian—a [illegible] in the northern part of the [illegible] States, extending from central New York State across Mi[chigan], including northern Pennsylvania and Ohio and part of south[ern] Ontario. Because of the hot, dry climate of that time, the sea lying over this place grew so salty that beds of salt [and] gypsum were deposited over a great area covering about 100 000 square miles. There are 7 distinct beds of salt at Ith[aca], New York, the uppermost lying at a depth of about half mile. In southern Michigan some of the individual salt [beds] are more than 500 feet thick, and the aggregate thickness [of] salt in the center of the Michigan Basin is approximate[ly] 2000 feet. In some places rock salt is mined. In others, wells are dug, water is forced down, and the resulting brine is pumped to the surface and evaporated to recover the salt.

One of the greatest stock piles of minerals in the world came from the evaporation of a great inland sea in the western United States. This is Searles Lake in the Mojave Desert of California. An arm of the sea that overlay this region was cut off from the [illegible] by the thrusting up of a range of mounta[ins] [illegible] lake [illegible] the water that remained be[illegible] [illegible] inwash of minerals from all [illegible] Lake began its slow tran[illegible] [illegible] zen lake—a lake of [illegible] [illegible] ago now its s[illegible] [illegible] may be driven. The [illegible] deep. Below that is

have recently discovered a second layer of salts and brine, probably at least as thick as the upper layer underlying the crust. Searles Lake was first worked in the 1870's for borax. Then teams of 20 mules each carried the borax across desert and mountains to the railroads. In the 1930's the recovery of other substances from the lake began—bromine, lithium, and salts of potassium and sodium. Now Searles Lake yields 40 per cent of the production of potassium chloride in the United States and a large share of the borax and lithium salts produced in the world.

In some future era the Dead Sea will probably repeat the history of Searles Lake, as the centuries pass and evaporation continues. The Dead Sea as we know it is all that remains of a much larger inland sea that once filled the entire Jordan Valley and was about 190 miles long; now it has shrunk to about a fourth of this length and a fourth of its former volume. And with the shrinkage and the evaporation in the hot dry climate has come the concentration of salts that makes the Dead Sea a great reservoir of minerals. No animal lif[illegible] can exist in its brine; such luckless fish as are brought down by the River Jordan die and provide food for the sea birds. It is 1300 feet below the Mediterranean, lying farther below sea level than any other body of water in the world. It occupies the lowest part of the rift valley of the Jordan, which was created by down-slipping of a block of the earth[illegible] crust. The water of the Dead Sea is warmer than the air[illegible] a condition f[illegible]voring evaporation, and clouds of its vapor float, nebulous and half formed, above it, while its brine grows more bitter and the salts accumulate.

Of all legacies of the ancient seas the most valuabl[illegible] petroleum. Exactly what geologic processes have created the precious pool of liquid deep within the earth no one knows w[illegible]h enough certainty to describe the whole sequence of events. But this much seems to be true: Petroleum is a result of fundamental earth processes that have been operating ever since an[illegible] abundant and varied lif[illegible] wa[illegible] developed in the sea—at least since the beginning of Paleozoic time, probably longer. Except[illegible] and catastrophic occurrences may now and then aid its f[illegible] but they are not essential; the mechanism that [illegible] erates petroleum consists of the normal processes of [illegible] sea—the living and dying of creatures, the depos[illegible] the advance and retreat of the seas over the continents [illegible] ward and downward foldings of the earth[illegible] crust.

The [illegible] inorganic theory that linked petroleum [illegible] with volcanic action ha[illegible] been abandoned by [illegible] The orig[illegible] petroleum is most likely to be f[illegible] of plants [illegible]nd animals buried under the [illegible] of former seas and there subjected to slow [illegible]

Perhaps the essence of conditions favoring petroleum duction is represented by the stagnant waters of the Black or of certain Norwegian fiords. The surprisingly abundant of the Black Sea is confined to the upper layers the especially the bottom waters are devoid of oxygen and often permeated with hydrogen sulphide. In these pole waters there can be no bottom scavengers to devour the bo of marine animals that drift down from above, so they are tombed in the fine sediments. In many Norwegian fiords deep layers are foul and oxygenless because the mouth of fiord is cut off from the circulation of the open sea by a shal sill. The bottom layers of such fiords are poisoned by the hyd gen sulphide from decomposing organic matter. Somet storms drive in unusual quantities of oceanic water turbulence of waves stir deeply the waters of these lethal ; the mixing of the water layers that follows brings death hordes of fishes and invertebrates living near the surface. a catastrophe leads to the deposit of a rich layer of material on the bottom.

Wherever great oil fields are found, they are related to or present seas. This is true of the inland fields as well as of near the present seacoast. The great quantities of oil that been obtained from the Oklahoma fields, for example, pped in spaces within sedimentary rocks laid down as that invaded this part of North America in Paleozo The search for petroleum has also led geologists to those 'unstable belts, covered much of the time by shal seas, which lie around the margins of the main conti platforms, between them and the great oceanic deeps.

An example of such a depressed segment of crust lying tween continental masses is the one between Europe and Near East occupied in part by the Persian Gulf, the Red, Black, and Caspian seas, and the Mediterranean Sea. The Gulf of Mexico and the Caribbean Sea lie in another basin or shallow sea between the Americas. A shallow island-studded sea lies between the continents of Asia and Australia. Lastly there is the nearly landlocked sea of the Arctic. In past ages all of these areas have been alternately raised and depressed, belonging at one time to the land, at another to the encroaching sea. During their periods of submersion they have received thick deposits of sediments, and in their waters a rich marine fauna has lived, died, and drifted down into the soft sediment carpet.

There are vast oil deposits in all these areas. In the Near East are the great fields of Saudi Arabia, Iran, and Iraq. The shallow depression between Asia and Australia yields the oil of Java, Sumatra, Borneo, and New Guinea. The American mediterranean is the center of oil production in the Western Hemi-

[illegible]—half the proved resources of the United States come from the northern shore of the Gulf of Mexico, and Colombia, Venezuela, and Mexico have rich oil fields along the western and southern margins of the Gulf. The Arctic is one of the unproved frontiers of the petroleum industry, but oil seepages in northern Alaska, on islands north of the Canadian mainland, and along the Arctic coast of Siberia hint that this land recently raised from the sea may be one of the great oil fields of the future.

In recent years, the speculations of petroleum geologists have been focused in a new direction—under sea. By no means all of the land resources of petroleum have been discovered, but probably the richest and most easily worked fields are being tapped, and their possible production is known. The ancient [illegible] gave us the oil that is now being drawn out of the earth. Can the ocean today be induced to give up some of the [illegible] that must be trapped in sedimentary rocks under its floor, covered by water scores or hundreds of fathoms deep?

Oil is already being produced from offshore wells on the continental shelf. Off California, Texas, and Louisiana, oil companies have drilled into the sediments of the shelf and are obtaining oil. In the United States the most active exploration has been centered in the Gulf of Mexico. Judging from its geologic history, this area has rich promise. For [illegible] it was either dry land or a very shallow sea basin, receiving sediments that washed into it from high lands [illegible]. Finally, about the middle of the Cretaceous period, the Gulf began to sink under the load of sediments, and it acquired its present deep central basin.

By geophysical exploration, we can see that the sedimentary rock underlying the coastal plain [illegible] ward and pass under the broad continental [illegible]. Down in the layers deposited in the Jurassic [illegible] salt bed of enormous extent, probably formed when the earth was hot and dry, [illegible] place of [illegible] encroaching deserts. In Louisiana and Texas [illegible] appears, out in the Gulf itself, [illegible] salt domes are associated with the [illegible]. These plugs of salt, usually less than [illegible] the deep layer toward the earth's surface [illegible] scribed by geologists as driven up [illegible] of sediment by earth pressure. [illegible] the states bordering the Gulf [illegible] associated with oil. It seems [illegible] shelf also the salt domes [illegible]

I[illegible] exploring the Gulf for [illegible] the salt domes where the [illegible]

use an instrument known as a magnetometer which measu the variations in magnetic intensity brought about by the domes. Gravity meters also help locate the domes by measur the variations in gravity near them, the specific gravity of being less than that of the surrounding sediments. The location and outline of the dome are discovered by graphic exploration, which traces the inclination of the strata by recording the reflection of sound waves produced dynamite explosions. These methods of exploration have used on land for some years, but only since about 1945 they been adapted to use in offshore Gulf waters. The tometer has been so improved that it will map continuo while being towed behind a boat or carried in or from a plane. A gravity meter can now be lowered rapidly the bottom and readings made by remote control. (Once operator had to descend with it in a diving bell.) Seismic now shoot off their dynamite charges and make recordings while their boats are under way

Despite all these improvements which allow exploration proceed rapidly it is no simple matter to obtain oil sea fields. Prospecting must be followed by the leasing of oil-producing areas, and then by drilling to see whether is actually there. Offshore drilling platforms rest on p must be driven as far as 250 feet into the floor of the Gulf withstand the force of waves, especially during the season hurricanes. Winds, storm waves, fogs, the corrosive sea water upon metal structures—all these are hazards must be faced and overcome. Yet the technical difficulties far more extensive offshore operations than any now attemp do not discourage specialists in petroleum engineering.

So our search for mineral wealth often leads us back to seas of ancient times—to the oil pressed from the bodies fishes, seaweeds, and other forms of plant and animal life then stored away in ancient rocks, to the rich brines hidden subterranean pools where the fossil water of old seas still mains to the layers of salts that are the mineral substance those old seas laid down as a covering mantle over the nents. Perhaps in time, as we learn the chemical secrets of corals and sponges and diatoms, we shall depend less on stored wealth of prehistoric seas and shall go more and m directly to the ocean and the rocks now forming under shallow waters.

*A sea from which birds travel not within year*
*so vast it is and fearful.*

HOMER

To the ancient Greeks the ocean was an endless stream that flowed forever around the border of the world, ceaselessly turning upon itself like a wheel, the end of earth, the beginning of heaven. This ocean was boundless; it was infinite. If a person were to venture far out upon it—were such a course thinkable—he would pass through gathering darkness and obscuring fog and would come at last to a dreadful and chaotic blending of sea and sky a place where whirlpools and yawning abysses waited to draw the traveler down into a dark world from which there was no return.

These ideas are found, in varying form, in much of the literature of the ten centuries before the Christian era, and in later years they keep recurring even through the greater part of the Middle Ages. To the Greeks the familiar Mediterranean was The Sea. Outside, bathing the periphery of the land world, was Oceanus. Perhaps somewhere in its uttermost expanse was the home of the gods and of departed spirits, the Elysian fields. So we meet the ideas of unattainable continents or of beautiful islands in the distant ocean, confusedly mingled with references to a bottomless gulf at the edge of the world—but always around the disc of the habitable world was the vast ocean, encircling all.

Perhaps some word-of-mouth tales of the mysterious northern world, filtering down by way of the early trade routes for amber and tin, colored the conceptions of the early legends, so that the boundary of the land world came to be pictured as a place of fog and storms and darkness. Homer Odyssey described the Cimmerians as dwelling in distant realm of mist and darkness on the shores of Oceanus, and told of the shepherds who lived in the land of the long day where the paths of day and night were close. And again perhaps the early poets and historians derived some of their ideas of the ocean from the Phoenicians, whose craft roamed the shores of Europe, Asia, and Africa in search of gold, silver, gems, spices, and wood for their commerce with kings and emperors. It may well be that these sailor-merchants were the first ever to cross an ocean, but history does not record the fact. For at least 000 years before Christ—probably longer—the flourishing trade of the Phoenicians was plied along the shores of the Red Sea to S ria, to

Somaliland, to Arabia, even to India and perhaps to C Herodotus wrote that they circumnavigated Africa from east west about 600 B.C., reaching Egypt via the Straits of the Pill and the Mediterranean. But the Phoenicians themselves and wrote little or nothing of their voyagings, keeping trade routes and the sources of their precious cargoes So there are only the vaguest rumors, sketchily supported archaeological findings, that the Phoenicians may launched out into the open Pacific.

Nor are there anything but rumors and highly plausible positions that the Phoenicians, on their coastwise along western Europe, may have sailed as far north as the dinavian peninsula and the Baltic, source of the precious ber There are no definite traces of any such visits by them, of course the Phoenicians have left no written record of Of one of their European voyages, however there is a hand account. This was the expedition under Himilco of thage, which sailed northward along the European coast the year 500 B.C. Himilco apparently wrote an account of voyage, although his manuscript was not preserved. But descriptions are quoted by the Roman Avienus, writi a thousand years later According to Avienus, Himilco a discouraging picture of the coastwise seas of Europe

These seas can scarcely be sailed through in four no breeze drives the ship forward, so dead is the sl wind of this idle sea There is much seaweed am waves the surface of the earth is barely covered by a l water The monsters of the sea move continually and thither and the wild beasts swim among the sluggish slowly creeping ships.

Perhaps the 'wild beasts' are the whales of the Bay of B later to become a famous whaling ground, the shallow w areas that so impressed Himilco may have been the flats nately exposed and covered by the ebb and flow of the tides of the French coast—a strange phenomenon to one the almost tideless Mediterranean. But Himilco also had of the open ocean to the west, if the account of Avienus is to trusted 'Farther to the west from these Pillars there is bo less sea None has sailed ships over these waters, propelling winds are lacking on these deeps likewise cause darkness screens the light of day with a sort of c. and because a fog always conceals the sea. Whether these scriptive details are touches of Phoenician canniness or the old ideas reasserting themselves it is hard to say but the same conceptions appear again and again in h echoing down the centuries to the very threshold of m. times.

So far as historical records are concerned, the first great voyage of marine exploration was by Pytheas of Massilia about 330 B.C. Unfortunately his writings, including one called *On the Ocean*, are lost and their substance is preserved for us only in fragmentary quotations passed on by later writers. We know very little of the controlling circumstances of the northward voyage of this astronomer and geographer but probably Pytheas wished to see how far the *oecumene* or land world extended, to learn the position of the Arctic Circle, and to see the land of midnight sun. Some of these things he may have heard of through the merchants who brought down tin and amber from the Baltic lands by the overland trade routes.

Since Pytheas was the first to use astronomical measurements to determine the geographic location of place and in other ways had proved his competence as a astronomer he brought more than ordinary skill to an exploratory voyage. H seems to have sailed around Great Britain, to have reached the Shetland Islands, and then to have launched out into the open ocean to the north, *coming at last to 'Thule the land of midnight sun.* In this country he is quoted as reporting, 'the nights were very short, in some places two in others three hours long, so that the sun rose again a short time after it had set. The country was inhabited by 'barbarians who showed Pytheas 'the place where the sun goes to rest. The location of 'Thule is a point much disputed by later authorities, some believing it to have been Iceland, while others believe that Pytheas crossed the North Sea to Norway Pytheas is also said to ha described a congealed sea lying north of Thule, which accords better with Iceland.

But the Dark Ages were settling dow over the civilized world, and little of the knowledge of distant places acqui ed by Pytheas on his voyagings seems to have impressed the learned men who followed him The geographer Posidonius wrot of the ocean that 'stretched to infinity' and from Rhodes he undertook a journey all the wa to Gadi (*Cadiz*) to see the ocean, measure its tides, and determine the truth of the belief that the sun dropped with the hissing of red-hot body into the great western sea.

N t for about 1200 years after Pytheas do we have another clear ccount of marine explor tion—this time by the Nor wegian Ottar Ottar described his voy g es in northern seas to King Alfred, who recorded them in straightforward narra tiv of geographic exploration strikingly f ee from sea monsters and other imaginary errors Otta on the basis of this account, was the first known explorer to round the North Cape, to enter the P la or Barents Sea, and later to enter the White Se found the coast f these seas inhabited by people of a seems to ha e heard previously According to the

the Pillars of Hercules as the gateway to a dreaded sea darkness.

Once Columbus had shown the way to the West Ind' the Americas, once Balboa had seen the Pacific and Magel had sailed around the globe, there arose, and long pers two new ideas. One concerned the existence of a northern sage by sea to Asia, the other had to do with a great continent generally believed to lie below the then-known

Magellan, while sailing through the strait that now name, had seen land to the south of him through all the seven days required for the passage through the strait. A. the lights of many fires glowed from the shores of this l which M gellan named Tierra del Fuego—Land of Fires. supposed that these were the near shores of that great which the theoretical geographers had already decided lie to the south.

Many voyagers after Magellan reported land they asser to be outlying regions of the sought for continent, but all to be islands. The locations of some, like Bouvet, were so definitely described that they were found and lost again times before being definitely fixed on maps. Kerguelen lieved firmly that the bleak, forbidding land he 1772 was the Southern Continent and so reported it to French government. When, on a later voyage, he learned he had found merely another island, Kerguelen named it 'Isle of Desolation. Later geographers, however his own name to it.

Discovery of the southern land was one of the objects of C tain Cook's voyages, but instead of a continent, he di an ocean. By making an almost complete circumnavigati the globe in high southern latitudes, Cook revealed the ence of a stormy ocean running completely around the south of Africa, Australia, and South America. Perhaps he lieved that the islands of the South Sandwich group were of the Antarctic mainland, but it is by no means sure that he the first to see these or other islands of the Antarctic American sealers had quite possibly been there before h yet this chapter of Antarctic exploration contains many b pages. The Yankee sealers did not want their competitors find the rich sealing grounds, and they kept the details voyages secret. Evidently they had operated in the vicinity the outer Antarctic islands for many years before the of the nineteenth century because most of the fur seals in waters had been exterminated by 1820. It was in this year the Antarctic continent was first sighted, by Captain N. Palmer in command of the *Hero* one of a fleet of eight from Connecticut ports. A century later explorers were stu

making fresh discoveries about the nature of that Southern Continent, dreamed of by the old geographers, so long searched for, then branded a myth, and finally established as one of the great continental masses of the earth.

At the opposite pole, meanwhile, the dream of a northern passage to the riches of Asia lured one expedition after another into the frozen seas of the north. Cabot, Frobisher and Davis sought the passage to the northwest, failed, and turned back. Hudson was left by a mutinous crew to die in an open boat. Sir John Franklin set out with the *Erebus* and *Terror* in 1845 apparently entered the labyrinth of Arctic islands by what later proved a feasible route, but then lost his ships and perished with all his men. Later rescue ships coming from east and west met in Melville Sound and thus the Northwest passage was established.

Meanwhile there had been repeated efforts to find a way to India by sailing eastward through the Arctic Sea. The Norwegians seem to have hunted walruses in the White Sea and had probably reached the coasts of Novaya Zemlya by the time of Other: they may have discovered Spitsbergen in 1194 although this is usually credited to Barents in 1596. The Russians had hunted seals in the polar seas as early as the sixteenth century and whalers began to operate out of Spitsbergen soon after Hudson, in 1607 called attention to the great number of whales in the sea between Spitsbergen and Greenland. So at least the threshold of the ice-filled northern ocean was known when the British and Dutch traders began their desperate [illegible]ttempt to find a sea road north of Europe and Asia. There were m[illegible]y [illegible]tempts, but few got beyond the coasts of Novay[illegible] Zemlya the sixteenth and seventeenth centuries were mark[illegible]d by the wreck age of hopes as well as of vessels and by the death [illegible]f such brilliant navigators as W[illegible]lliam Barents under the hardships met by expeditions ill prepared f[illegible]r arctic winters. [illegible]inall[illegible] the ef[illegible] was abandoned. It w[illegible] [illegible] until 1879 [illegible]fter the pre[illegible] [illegible]al com[illegible] for such [illegible] passage had largely disappeared, tha[illegible] Bar[illegible] [illegible]kiöld, in the Swedish *V[illegible]ga* passed from Gothenbu[illegible]g to Bering Strait.

So little by little, through many voy[illegible]ges undertaken [illegible] many centuries, the f[illegible]g and the frightening [illegible] unknown were lifted from all the surfac[illegible] [illegible] the sea [illegible] How did they accomplish it—those fir[illegible] voyage[illegible] not even the simplest instruments of navigat[illegible]on [illegible] seen [illegible] nautical chart, to whom the modern [illegible] radar, and sonic soundings would hav[illegible] been [illegible] belief? Who was the first man to use a[illegible] [illegible] what were the embryonic beginnings [illegible] sailing directions that are taken for granted

these questions can be answered with finality we know enough to want to know more.

Of the methods of those secretive master mariners, Phoenicians, we cannot even guess. We have more basis conjecture about the Polynesians, for we can study their scendants today and those who have done so find hints of methods that led the ancient colonizers of the Pacific on course from island to island. Certainly they seem to have lowed the stars, which burned brightly in the heavens calm Pacific regions, which are so unlike the stormy and bound northern seas. The Polynesians considered the stars moving bands of light that passed across the inverted pit of y and they sailed toward the stars which they knew p the islands of their destination. All the l as understood by them the varying color of the water haze of surf breaking on rocks yet below the horizon, and cloud patches that hang over every islet of the tropic seas sometimes seem even to reflect the color of a lagoon within coral atoll.

Students of primitive navigation believe that the migrat birds had meaning for the Polynesians, and that they learr much from watching the flocks that gathered each year in spring and fall, launched out over the ocean, and returned out of the emptiness into which they had vanished. Haro Gatty believes the Hawaiians may have found their is following the spring migration of the golden plover from to the Hawaiian chain, as the birds returned to the American mainland. He has also suggested that the migrat path of the shining cuckoo may have guided other co from the Solomons to New Zealand.

Tradition and written records tell us that primitive navigators often carried with them birds which they would release and follow to land. The frigate bird or man-of-war bird was the shore-sighting bird of the Polynesians (even in recent times it has been used to carry messages between islands) and in the Norse Sagas we have an account of the use of 'ravens by Flok Vilgerdarson to show him the way to Iceland, 'since seafaring men had no loadstone at that time in the north Thence he sailed out to sea with the three ravens And when he let loose the first it flew back astern. The second flew up into the air and back to the ship. The third flew forward over the prow where they found land.

In thick and foggy weather according to repeated statements in the Sagas, the Norsemen drifted for days without knowing where they were. Then they often had to rely on observing the flight of birds to judge the direction of land. The *Landnamabok* says that on the course from Norway to Green-

led the voyager should keep far enough to the south of Iceland to have birds and whales from there. In shallow waters it appears that the Norsemen took some sort of soundings, for the *Historia Norwegiae* records that Ingolf and Hjorleif found Iceland by probing the waves with the lead.

The first mention of the use of the magnetic needle as a guide to mariners occurs in the twelfth century after Christ, but as much as a century later scholars were expressing doubt that sailors would entrust their lives to an instrument so obviously invented by the devil. There is fair evidence, however that the compass was in use in the Mediterranean about the end of the twelfth century and in northern Europe within the next hundred years.

For navigating the known seas, there had been the equivalent of our modern Sailing Directions for great many centuries before this. The *portolano* and the *periplii* guided the mariners of antiquity about the Mediterranean and Black seas. The *portolano* were harbor-finding charts, designed to accompany the coast pilots or *periplii*, and it is not known which of the two was developed first. The *Periplus of Scylax* is the oldest and most complete of these ancient Coast Pilots that have survived the hazards of the intervening centuries and are preserved for us. The chart which presumably accompanied it no longer exists, but the two were, in effect, a guide to navigation of the Mediterranean in the fourth or fifth century B

The *periplus* called *Stadiasmus, or circumnavigation* [illegible] great sea dates from about the fifth century fter Christ but reads surprisingly like a modern Pilot, giving distances be ween points, the winds with which the various island migh be approached, and the facilities for anchorage or f r obt ning fresh water So for example, we read, 'From Hermae [illegible] 20 stadia hereby lies a low islet at a distance of [illegible] the land, there is anchorage for cargo boats, [illegible] west wind but by the shore below the promon [illegible] anchoring-road for all kinds of vessels T mpl [illegible] famous oracle by the temple there is wat

Lloyd Brown, in his *Story of Maps* sa [illegible] ners chart of the first thousand years [illegible] preserved or is definitely known to have [illegible] to the fact tha early mariners carefull guarded the secrets of how they made their passages from pla [illegible] place that such charts were 'keys to empire' and 'way [illegible] and as such were secret, hidden documents. Therefore because the earliest specimen f such chart now extant w made by Petrus [illegible] ...conte in 1311 does not mean that many had bef re it

I was Dutchman who produced the

gational charts bound together in book form—Lucas Waghenaer. The *Mariner's Mirror* of Waghenaer first [illegible] lished in 1584 covered the navigation of the western coast Europe from the Zuyder Zee to Cadiz. Soon it was issued several languages. For many years 'Waggoners' guided [illegible] English, Scandinavian, and German navigators through Atlantic waters, from the Canaries to Spitsbergen. [illegible] ing editions had extended the areas covered to include the [illegible] lands and Faroe Islands and even the northern coast of [illegible] as far as Novaya Zemlya.

In the sixteenth and seventeenth centuries, under the [illegible] of fierce competition for the wealth of the East Indies, [illegible] charts were prepared not by governmental agencies, [illegible] ise. The East India companies employed th[illegible] own hydrographers, prepared secret atlases, and genera[illegible] guarded their knowledge of the sailing passages to the East one of the most precious secrets of their trade. But in 1795 [illegible] East India Company's hydrographer, Alexander Dalrympl[illegible] became official hydrographer to the Admiralty and under direction the British Admiralty began its survey of the [illegible] the world from which the modern Admiralty Pilots [illegible]

[illegible]ortly thereafter a young man joined the United [illegible]avy—Matthew Fontaine Maury. In only a few years [illegible] ant Maury was to make his influence felt on navigation over the world, and was to write a book, *The Physical G[illegible] phy of the Sea*, which is now considered a foundation of th[illegible] science of oceanography. After a number of years at [illegible] Maury assumed charge of the Depot of Charts and Instrumen[illegible] —the forerunner of the present Hydrographic Office—and began a practical study of winds and currents from the standpoint of the navigator. Through his energy and initiative a world-wide co-operative system was organized. Ships' officers of all nations sent in the logs of their voyages, from which Maury assembled and organized information, which he incorporated in navigational charts. In return, the co-operating mariner received copies of the charts. Soon Maury's sailing directions were attracting world notice: he had shortened the passage for American east-coast vessels to Rio de Janeiro by 10 days, to Australia by 20 days, and around the Horn to California by 30 days. The co-operative exchange of information sponsored by Maury remains in effect today, and the Pilot Charts of the Hydrographic Office, the lineal descendants of Maury's charts, carry the inscription: 'Founded on the researches of Matthew Fontaine Maury [illegible] e serving as a Lieutenant in the United States Navy.'

In the modern [illegible], Directions and Coast Pilots now issued by every [illegible] of the world we find the most com-

the information that is available to guide the navigator over the ocean. Yet in these writings of the sea there is a pleasing kind of modernity and antiquity with unmistakable touches by which we may trace their lineage back to the sailing directions of the sagas or the *periplus* of the ancient Mediterranean ...

It is surprising, but pleasant, that sailing directions of one and the same vintage should contain instructions for obtaining positions by the use of loran, and should also counsel the navigator to be guided, like the Norsemen a millennium ago, by the flight of birds and the behavior of whales in making land in foggy weather. In the *Norway Pilot* we read as follows

[Of Jan Mayen Island] The presence of sea fowl in large numbers will give an indication of the approach to land and the noise of their rookeries may be useful in locating the shore.

[Of Bear Island] The sea around the islands teems with guillemots. These flocks and the direction of their flight on approaching, together with the use of the lead, are of great value in making the island when it is foggy.

And the ultra-modern United States Pilot for Antarctica says,

"Navigators should observe the bird life, for deductions may often be drawn from the presence of certain species. Shags are a sure sign of the close proximity of land ... The snow petrel is invariably associated with ice and is of great interest to mariners as an augury of ice conditions ... Blowing whales usually travel in the direction of open water

Sometimes the Pilots let [illegible] ... of the sea can report only what the whalers or sealers or some old-time fisherman has said about the navigability of a channel or the set of the tidal currents; or they must include a chart prepared half ... century ago by the last vessel to take soundings in the area. Often they must caution the navigator not to proceed without seeking information of those having local knowledge. In phrases ... these we get the feel of the unknown and the mysterious ... never quite separated itself from the sea. "It is said that ... was once an island there ... such information as could be secured from reports of men with local knowledge ... position has been disputed ... that reported by an ... sealer ... out ... Office ...

So here and there, in a few ... of antiquity still lingers ... is rapidly being dispelled ... surface of the ... of the ocean is known ... also the ... we can still apply ... It took centuries to chart ... in delineating the waters ...

phenomenally rapid. But even with all our m for probing and sampling the deep ocean, no one now can that we shall ever resolve the last, the ultimate my the sea.

In its broader meaning, that other concept of the ancients mains. For the sea lies all about us. The commerce of all must cross it. The very winds that move over the lands been cradled on its broad expanse and seek ever to return The continents themselves dissolve and pass to the sea, in after grain of eroded land. So the rains that rose from it again in rivers. In its mysterious past it encompasses all dim origins of life and receives in the end, after it may be, transmutations, the dead husks of that same life. For all at return to the sea—to Oceanus, the ocean river like the e flowing stream of time the beginning and the end.

# Suggestions for Further Reading

## General Information About the Ocean and Its Life.


Bigelow, Henry B., and Edmondson, W. T. *Wind Waves at Sea, Breakers and Surf*, U.S. Navy Hydrographic Office Pub. no. 602. Washington: U.S. Government Printing Office, 1947. 177 pp. *Extremely readable; full of interesting and practical information about waves at sea and along coasts.*

Coker, R. E. *This Great and Wide Sea*. Chapel Hill: University of North Carolina Press, 1947. 325 pp. *A scholarly treatment of the subject of oceanography recommended for serious students.*

Johnson, Douglas W. *Shore Processes and Shoreline Development*. New York, John Wiley and Sons, 1919. 584 pp. *Primarily for geologists and engineers concerned with shoreline changes, yet the chapter "The Work of Waves" is unmatched for sheer interest.*

Marmer, H. A. *The Sea*. New York, D. Appleton and Co. 1930. 312 pp. *A concise and scholarly account for the general reader; stresses physical oceanography.*

*The Tide*, New York, D. Appleton and Co. 1926. 282 pp. [illegible] *book the outstanding American authority on tidal phenomena explains the complex behavior of the tides.*

Maury, Matthew Fontaine, *Physical Geography of the Sea*. New York, Harper and Brothers, 1855. [illegible] pp. *Marks the foundation of the science of oceanography, as the first book to consider the sea as a dynamic whole.*

Murray, Sir John, and Hjort, Johan, *The Depths of the Ocean*. London, Macmillan, 1912. [illegible] pp. *Based chiefly on the work of the Norwegian research vessel Michael Sars in the North Atlantic. This work was for many years the bible of oceanography. It is now out of print and copies are rare.*

National Research Council, Oceanography, Bulletin no. 85 (in Physics of the Earth series). Washington, 1932. [illegible] pp. *A summary of our knowledge (pre-Second World War) of the ocean. Many chapters are not [illegible] informative but highly readable.*

Ommanney, F. D. *The Ocean*. London, Oxford University Press, [illegible] [illegible] pp. *A thoughtful and pleasantly written account of the ocean and its life for the general reader.*

Russell, F. S. and Yonge, C. M. *The Seas*. London, Frederick Warne and Co., [illegible] 379 pp. *Written chiefly from the biological point [illegible] this is one of the best general treatments of the subject.*

Sverdrup, H. U., Fleming, Richard, and Johnson, Martin W. *The [illegible]*. New York, Prentice Hall, Inc., 1942. 1087 pp. *The standard [illegible] textbook of oceanography.*


Some of the most rewarding sources of information [illegible] are the Sailing Directions of the U. S. Hydrographic [illegible] waters outside of the United States) and the Coast [illegible] U. S. Coast and Geodetic Survey (for United States [illegible]

giving detailed accounts of the coastlines and coastal waters world, these books are repositories of fascinating informat icebergs and sea ice, storms, and fog at sea. Some approa character of regional geographies. Those dealing with remot inaccessible coasts are especially interesting. They may b chased from the issuing agency. The British Admiralty publi similar series, as do the ppropriate authorities of most ma nations.

## *Sea Lif In Relation to Its Surroundings.*

Hesse, Richard, Allee, W. C., and Schmidt, Karl P. *Ecological A Geography* New York, John Wiley and Sons, 1937. 597 pp. *This excellent source of information on the intricate relations ) living thin their environment with profuse references to source material. Abo fourth ) the book is concerned with marine animals.*

Murphy Robert Cushman. *Oceanic Birds ) South America.* New Y Macmillan, 1948. 1245 pp. 2 vols. (originally issued by American Mu of Natural History 1936). *Highl recommended for an underst ing ) the relation of birds to the sea and of marine organisms to t environment. It describes little-known shores and islands in extre readable prose and contains an extensive bibliography.*

Wallace Alfred Russell. *Island Life* London, Macmillan, 1880. 526 *Deal in interesting fashion with th basic biology ) island life.*

Yonge C. M. *The Se Shore.* London, Collins, 1949. 311 pp. *the general reader, charming and authoritative account of the life ) s based chiefly on British localities.*

E. F. and Calvin Jack. *Between Pacific Tides* Stanford, Sta niversity Press, 1948. 365 pp. *A ideal companion for explo merican Pacific shores.*

## *Exploration and Discovery*

Babcock, William H. *Legendary Islands ) the Atlantic study medieval geography* New York, American Geographical Society 315 pp. *Deals with early exploration of the sea and the search distant lands.*

Beebe, William. *Half Mile Down.* New York, Harcourt Brace, 1934 344 pp. *Stands alone as vivid eyewitness account ) the sea hal below the surface.*

Brown, Lloyd A. *The Story of M ps.* Boston, Little, Brown, 1949. 397 pp. *Contains, especially in the chapter The Haven Finding Art, much ) interest bout early voyages.*

Challenger Staff. *Report on the Scientific Results of th Exploring Voy ge ) H. M. S. Challenger, 1873-76.* 40 vols. *See especially volume 1 parts 1 and 2—Narrative of the Cruise—which give an interesting account of this historic expedition.*

Darwin Charles. *The Diary of the V yage ) H. M. S. Beagle.* Edited from the manuscript by Nora Barlow, Cambridge Cambridge University Press, 1934. 51 pp. *A fresh and charming account. Darwin actually set it down in the course ) the Beagle voyage.*

Heyerdahl, Thor. *Kon-Tiki.* Chicago Rand McNall & Co., 1950. 304 pp. *The Od sey ) 1 modern Vikings who crossed the Pacific on* ... *1950—one ) the great books ) the sea.*

Gilbert. *Lorpsa*. New York, Dodd, Mead and Co., 1940. 383 pp. *and experiences [illegible] modern cast-away on [illegible] lonely island, and later undersea explorations of his [illegible]; delightful reading.*

[illegible], Phillip, J. *Northern Mists*. Cleveland, A. H. Clark, 1912. 2 [illegible] *One of the most comprehensive reviews of early sea voyages.*

## History of Earth and Sea

Brooks, C. E. P. *Climate Through the Ages*. New York, McGraw-Hill, 192[illegible]. 3[illegible] pp. *Interprets clearly and readably the climatic changes [illegible] the ages.*

Coleman, A. P. *Ice Ages, Recent and Ancient*. New York, Macmillan, 19[illegible]. 29[illegible] pp. *A[n] account of Pleistocene glaciation, and also [of] earlier [illegible] epochs.*

Daly, Reginald. *The Changing World of the Ice Age*. New Haven, Yale [Univ]ersity Press, 1934. 271 pp. *A fresh, stimulating, and vigorous treatment of the subject; more easily read, however, against some background of geology.*

[illegible]. *Our Mobile Earth*. New York, Charles Scribner's Sons, 1926. 342 pp. *For the general reader; an excellent picture [of] the earth's constant[ly] [illegible] development.*

Moore, Raymond C. *Historical Geology: The Geological History of North America*. New York and London, McGraw-Hill, 1933. 443 pp.

Miller, William J. *A[n] Introduction to Historical Geology with Special Reference to North America*. New York, D. Van Nostrand Co. 1937. [illegible] pp.

Schuchert, Charles, and Dunbar, Carl O. *Outlines [of] Historical Geology*. New York, John Wiley and Sons, 1941. 291 pp. *Any one [of] these [five] books will give the general reader [a] good conception [of] this fascinating subject; the treatment by the various authors differs enough that all may be read with profit.*

Shepard, Francis P. *Submarine Geology*. New York, Harper and Brothers, 194[illegible]. [illegible] pp. *The first textbook in [a] field which is still in the pioneering stages.*

## Outstanding Sea Prose

These books are listed because each, in one way or another, captures the sea['s] varied and always changing moods. All are among my own favorite volumes.

Beston, Henry. *The Outermost House: A Year of Life on the Great Beach of C[ape Cod]*. New York, Rinehart and Company, [illegible]. 222 pp.

Conrad, Joseph. *The Mirror of the Sea*. New York, Doubleday [illegible], 1913. 194 pp.

Hughes, Richard. *[illegible] Harard*. New York, Harper and Brothers, [illegible] pp. ([illegible] published by Penguin Books, 1943).

Melville, Herman. *Moby Dick*.

Nordhoff, Charles, and Hall, James Norman. *Men Against [the Sea]*. Boston, [illegible] Brown, [illegible]. 251 pp. (Also published by [illegible] 1946).

Tomlinson, H. [illegible] *Sea and the Jungle*. New [illegible] 1913. 332 pp.

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